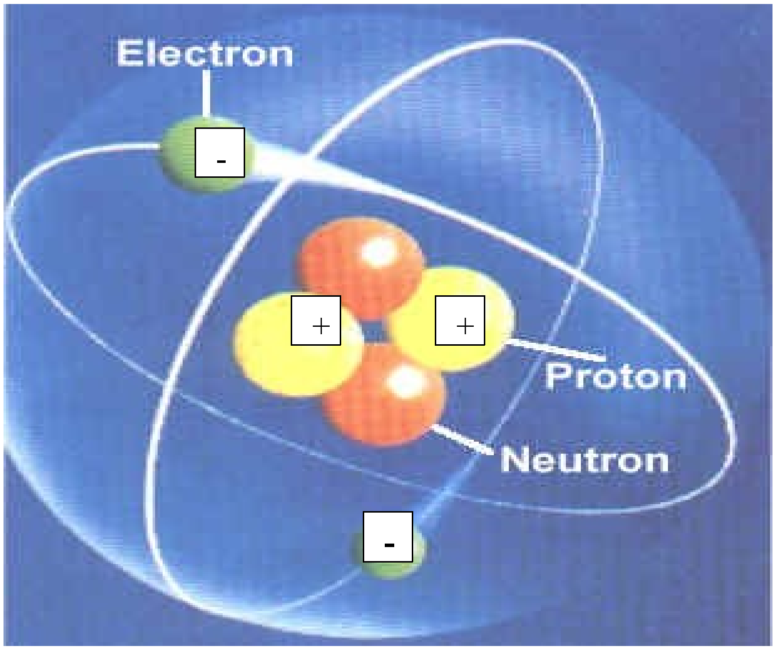
Atom



The **atom** is a basic unit of matter consisting of a dense, central nucleus surrounded by a cloud of negatively charged electrons. The atomic nucleus contains a mix of positively charged protons and electrically neutral neutrons (except in the case of Hydrogen-1, which is the only stable nuclide with no neutron). The electrons of an atom are bound to the nucleus by the electromagnetic force. Likewise, a group of atoms can remain bound to each other, forming a molecule. An atom containing an equal number of protons and electrons is electrically neutral, otherwise it has a positive or negative charge and is an ion. An atom is classified according to the number of protons and neutrons in its nucleus: the number of protons determines the chemical element, and the number of neutrons determine the isotope of the element.

Electron

The **electron** is a subatomic particle that carries a negative electric charge. It has no known substructure and is believed to be a point particle.[2] Electrons participate in gravitational, electromagnetic and weak interactions. Like its rest mass and elementary charge, the intrinsic angular momentum (or spin) of an electron has a constant value. In the collision of an electron and a positron, the electron's antiparticle, both are annihilated. An electron–positron pair can be produced from gamma ray photons with sufficient energy.

Proton

The **proton** is a subatomic particle with an electric charge of +1 elementary charge. It is found in the nucleus of each atom but is also stable by itself and has a second identity as the hydrogen ion, H^+. It is composed of 3 even more fundamental particles comprising two up quarks and one down quark.

Neutron

The **neutron** is a subatomic particle with no net electric charge and a mass slightly larger than that of a proton.

Neutrons are usually found in atomic nuclei. The nuclei of most atoms consist of protons and neutrons, which are therefore collectively referred to as nucleons. The number of protons in a nucleus is the atomic number and defines the type of element the atom forms. The number of neutrons determines the isotope of an element. For example, the carbon-12 isotope has 6 protons and 6 neutrons, while the carbon-14 isotope has 6 protons and 8 neutrons.

Electrical conductor

In science and engineering, an electrical **conductor** is a material which contains movable electric charges. In metallic conductors, such as copper or aluminum, the movable charged particles are electrons (See electrical conduction). Positive charges may also be mobile in the form of atoms in a lattice missing electrons (called "holes") or ions, such as in the electrolyte of a battery.

Note: The following applies to direct current only. When the direction of voltage/current alternates, other effects (inductive and capacitive reactance) come into play also.

All conductors contain electric charges which will move when an electric potential difference (measured in volts) is applied across separate points on the material. This flow of charge (measured in amperes) is what is meant by *electric current*. In most materials, the rate of current is proportional to the voltage (as determined by Ohm's law) provided the temperature remains constant and the material remains in the same shape and state.

Most familiar conductors are metallic. Copper is the most common material for electrical wiring (silver is the best but expensive), and gold for high-quality surface-to-surface contacts. However, there are also many non-metallic conductors, including graphite, solutions of salts, and all plasmas. See electrical conduction for more information on the physical mechanism for charge flow in materials.

Non-conducting materials lack mobile charges, and so resist the flow of electric current, generating heat. In fact, all non-superconducting materials offer some resistance and warm up when a current flows. Thus, proper design of an electrical conductor takes into account the temperature that the conductor needs to be able to endure without damage, as well as the quantity of electrical current. The motion of charges also creates an electromagnetic field around the conductor that exerts a mechanical radial squeezing force on the conductor. A conductor of a given material and volume (length x cross-sectional area) has no real limit to the current it can carry without being destroyed as long as the heat generated by the resistive loss is removed and the conductor can withstand the radial forces. This effect is especially critical in printed circuits, where conductors are relatively small and close together, and inside an enclosure: the heat produced, if not properly removed, can cause fusing (melting) of the tracks.

Since all non-superconducting conductors have some resistance, and all insulators will carry some current, there is no theoretical dividing line between conductors and insulators. However, there is a large gap between the conductance of materials that will carry a *useful current* at working voltages and those that will carry a negligible current for the purpose in hand, so the categories of *insulator* and *conductor* do have practical utility.

Thermal and electrical conductivity often go together (for instance, most metals are both electrical and thermal conductors). However, some materials are practical electrical conductors without being a good thermal conductor.

(Electrical) Non Conductor (Insulator)

An **insulator**, also called a *dielectric*, is a material that resists the flow of electric current. An insulating material has atoms with tightly bonded valence electrons. These materials are used in parts of electrical equipment, also called *insulators* or *insulation*, intended to support or separate electrical conductors without passing current through themselves. The term is also used more specifically to refer to insulating supports that attach electric power transmission wires to utility poles or pylons.

Some materials such as glass or Teflon are very good electrical insulators. A much larger class of materials, for example rubber-like polymers and most plastics are still "good enough" to insulate electrical wiring and cables even though they may have lower bulk resistivity. These materials can serve as practical and safe insulators for low to moderate voltages (hundreds, or even thousands, of volts).

Semiconductor

A **semiconductor** is a material that has electrical conductivity between those of a conductor and an insulator. The conductivity of a semiconductor material can be varied under an external electrical field. Devices made from semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices. Semiconductor devices include the transistor, many kinds of diodes including the light-emitting diode, the silicon controlled rectifier, and digital and analog integrated circuits. Solar photovoltaic panels are large semiconductor devices that directly convert light energy into electrical energy.

In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current can be carried either by the flow of electrons or by the flow of positively-charged "holes" in the electron structure of the material.

Silicon is used to create most semiconductors commercially. Dozens of other materials are used, including germanium, gallium arsenide, and silicon carbide. A pure semiconductor is often called an “intrinsic” semiconductor. The conductivity, or ability to conduct, of semiconductor material can be drastically changed by adding other elements, called “impurities” to the melted intrinsic material and then allowing the melt to solidify into a new and different crystal. This process is called "doping".

CURRENT:

The flow of Electron through a conductor is called current. The no. of electronics moving through a conductor per second called Ampere.

The unit of current is **"Ampere".**

Sub Unit:

nA	= Nano Ampere	= 10^{-9}	= 1/1000000000
µA	= Micro Ampere	= 10^{-6}	= 1-1000000
mA	= Milli Ampere	= 10^{-3}	= 1/1000
A	= Ampere	= 1	
KA	= Kilo Ampere	= 10^{3}	= 1000
MA	= Mega Ampere	= 10^{6}	= 1000000
GA	= Giga Ampere	= 10^{9}	= 1000000000

current Conversion:

1000 nA = 1 µA

1000 µ A = 1 mA

1000 mA = 1 A

1000 A = 1 KA

1000 KA = 1 MA

1000 MA = 1 GA

Types of Current:
There are two types 1. AC Current
2. DC Current

AC – Current & DC - Current

Alternating Current (AC)

Alternating Current (AC) flows one way, then the other way, continually reversing direction.

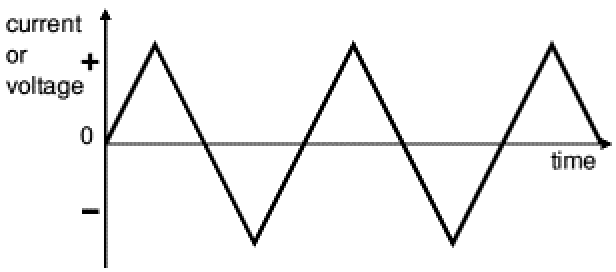
An AC voltage is continually changing between positive (+) and negative (-).

The rate of changing direction is called the **frequency** of the AC and it is measured in **hertz (Hz)** which is the number of forwards-backwards **cycles per second**.

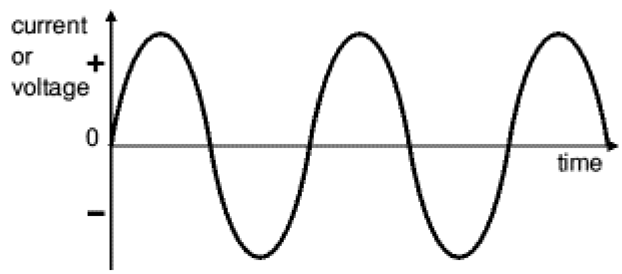
Mains electricity in the UK has a frequency of 50Hz.

See below for more details of signal properties.

An AC supply is suitable for powering some devices such as lamps and heaters but almost all electronic circuits require a steady DC supply (see below).



This triangular signal is AC because it changes between positive (+) and negative (-).



AC from a power supply
This shape is called a **sine wave**.

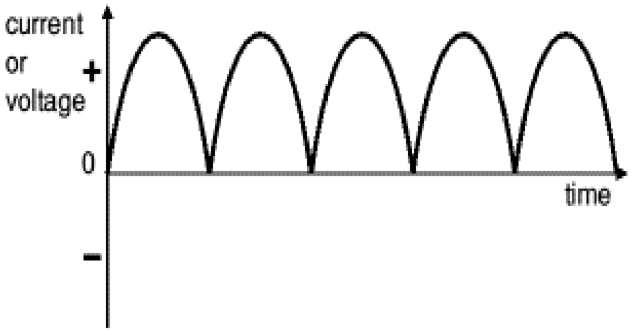
Direct Current (DC)

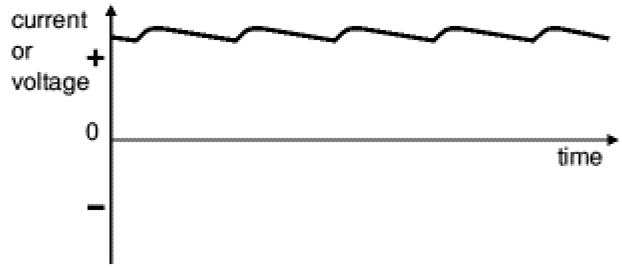
Direct Current (DC) always flows in the same direction, but it may increase and decrease.

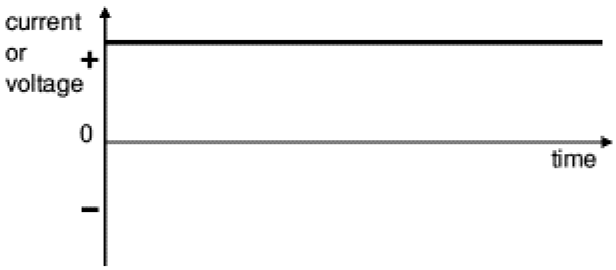
A DC voltage is always positive (or always negative), but it may increase and decrease.

Electronic circuits normally require a **steady DC** supply which is constant at one value or a **smooth DC** supply which has a small variation called **ripple**.

Cells, batteries and regulated power supplies provide **steady DC** which is ideal for electronic circuits.







Power supplies contain a transformer which converts the mains AC supply to a safe low voltage AC. Then the AC is converted to DC by a bridge rectifier but the output is **varying DC** which is unsuitable for electronic circuits.

Some power supplies include a capacitor to provide **smooth DC** which is suitable for less-sensitive electronic circuits, including most of the projects on this website.

Lamps, heaters and motors will work with any DC supply.

Voltage

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What is voltage?
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Voltage is a measure of the electric force available to cause the movement or flow of electrons. Thus, voltage in itself implies no movement of electrons, but the potential to cause electrons to move.

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Voltage measurements of direct current
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When an electric force is available to cause the movement of electrons, a voltmeter is used to measure the potential. When that potential is unchanging, it is said to be a direct current or DC potential. DC electricity typically comes from a battery, but may come from a filtered, rectified power supply. More on rectification and filtering later.

Voltage measurements of alternating current

When an electrical force is available to cause the movement of electrons, it can sometimes not be measured accurately because the value is changing instant-by-instant. In a typical generator, for example, it can be changing in value between -110Volts and +110 volts in a sinusoidal (sine wave) fashion. Voltage that changes instant-by-instant, such as your household power, is called AC or Alternating Current.

In these cases, a rectified value is extracted and filtered in order that an average, 'positive' voltage value can be measured. More on the mechanism of rectification later but know that this is a method of converting AC into DC electricity.

Voltage:

The difference of Electric potential which exists between two points of conduction carrying a constant of one Ampere. When the power dissipate between these points in one watt.

The unit of Voltage **"Volt" = V**

nV = Nano Volt = 10^{-9} = 1/1000000000
µV = Micro Volt = 10^{-6} = 1-1000000
mV = Milli Volt = 10^{-3} = 1/1000
V = Volt = 1
KV = Kilo Volt = 10^{3} = 1000
MV = Mega Volt = 10^{6} = 1000000
GV = Giga Volt = 10^{9} = 1000000000

Current Conversion:

1000 nV = 1 µV

1000 µ V = 1 mV

1000mV = 1 V

1000 V = 1 KV

1000 KV = 1 MV

1000 MV = 1 GV

There are two types of Voltage

AC Voltage & DC Voltage.

Electric power

Electric power is defined as the rate at which electrical energy is transferred by an electric circuit. The SI unit of power is the watt.

When electric current flows in a circuit, it can transfer energy to do mechanical or thermodynamic work. Devices convert electrical energy into many useful forms, such as heat (electric heaters), light (light bulbs), motion (electric motors), sound (loudspeaker) or chemical changes. Electricity can be produced mechanically by generation, or chemically, or by direct conversion from light in photovoltaic cells, also it can be stored chemically in batteries.

The electric power in watts associated with a complete electric circuit or a circuit component represents the rate at which energy is converted from the electrical energy of the moving charges to some other form, e.g., heat, mechanical energy, or energy stored in electric fields or magnetic fields. For a resistor in a D C Circuit the power is given by the product of applied voltage and the electric current:

P = VI

Power = Voltage x Current

Watts = volts x amperes

Enter data in any two of the boxes, then click on the active text for the quantity you wish to calculate.

Ohm's law

$$\frac{V}{I * R}$$

V = I*R
I = V/R
R =V/I

Ohm's law applies to electrical circuits; it states that the current through a conductor between two points is directly proportional to the potential difference or voltage across the two points, and inversely proportional to the resistance between them.

The mathematical equation that describes this relationship is:

Where I is the current in amperes, V is the potential difference in volts, and R is a circuit parameter called the resistance (measured in ohms, also equivalent to volts per ampere). The potential difference is also known as the voltage drop, and is sometimes denoted by U, E or emf (electromotive force) instead of V.

The law was named after the German physicist Georg Ohm, who, in a treatise published in 1827, described measurements of applied voltage and current through simple electrical circuits containing

various lengths of wire. He presented a slightly more complex equation than the one above to explain his experimental results. The above equation is the modern form of Ohm's law.

The resistance of most resistive devices (resistors) is constant over a large range of values of current and voltage. When a resistor is used under these conditions, the resistor is referred to as an *ohmic device* (or an *ohmic resistor*) because a single value for the resistance suffices to describe the resistive behavior of the device over the range. When sufficiently high voltages are applied to a resistor, forcing a high current through it, the device is no longer ohmic because its resistance, when measured under such electrically stressed conditions, is different (typically greater) from the value measured under standard conditions (see temperature effects, below).

Ohm's law, in the form above, is an extremely useful equation in the field of electrical/electronic engineering because it describes how voltage, current and resistance are interrelated on a "macroscopic" level, that is, commonly, as circuit elements in an electrical circuit. Physicists who study the electrical properties of matter at the microscopic level use a closely related and more general vector equation, sometimes also referred to as Ohm's law, having variables that are closely related to the I, V and R scalar variables of Ohm's law, but are each functions of position within the conductor. See the Physics and Relation to heat conduction sections below.

Electrical circuits consist of electrical devices connected by wires (or other suitable conductors). (See the article electrical circuits for some basic combinations.) The above diagram shows one of the simplest electrical circuits that can be constructed. One electrical device is shown as a circle with + and - terminals, which represents a voltage source such as a battery. The other device is illustrated by a zig-zag symbol and has an R beside it. This symbol represents a resistor, and the R designates its resistance. The + or positive terminal of the voltage source is connected to one of the terminals of the resistor using a wire of negligible resistance, and through this wire a current I is shown, in a specified direction illustrated by the arrow. The other terminal of the resistor is connected to the - or negative terminal of the voltage source by a second wire. This configuration forms a complete circuit because all the current that leaves one terminal of the voltage source must return to the other terminal of the voltage source. (While not shown, because electrical engineers assume that it exists, there is an implied current I, and an arrow pointing to the left, associated with the second wire.)

Voltage is the electrical driver that moves (negatively charged) electrons through wires and electrical devices, current is the rate of electron flow, and resistance is the property of a resistor (or other device that obeys Ohm's law) that limits current to an amount proportional to the applied voltage. So, for a given resistance R (ohms),

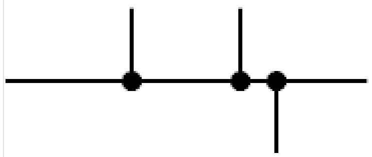
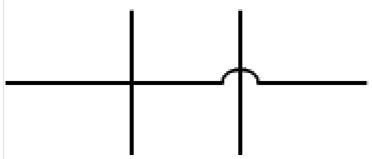
and a given voltage V (volts) established across the resistance, Ohm's law provides the equation (I=V/R) for calculating the current through the resistor (or device).

The "conductor" mentioned by Ohm's law is a circuit element across which the voltage is measured. Resistors are conductors that slow down the passage of electric charge. A resistor with a high value of resistance, say greater than 10 megohms, is a poor conductor, while a resistor with a low value, say less than 0.1 ohm, is a good conductor. (Insulators are materials that, for most practical purposes, do not allow a current when a voltage is applied.)

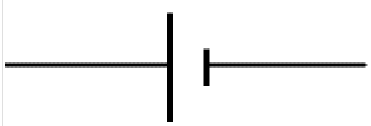
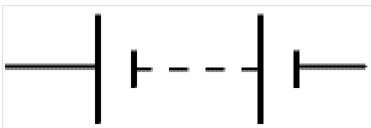
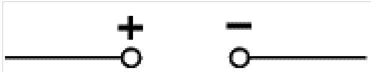
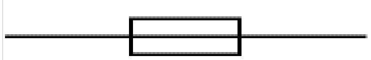
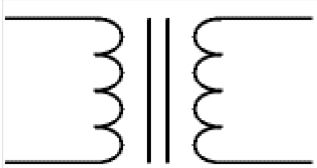
In a circuit diagram, like the one above, the various components may be joined by connectors, contacts, welds or solder joints of various kinds, but for simplicity these connections are usually not shown.

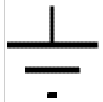
Electronic Symbols

Wires and connections

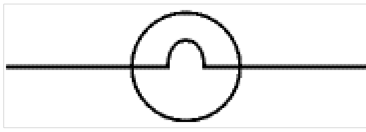
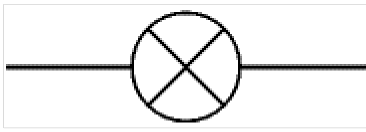
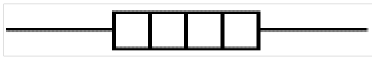
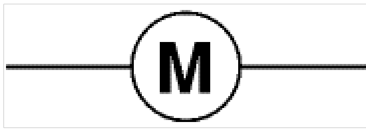
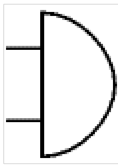
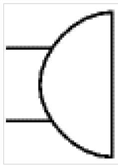
Component	Circuit Symbol	Function of Component
Wire		To pass current very easily from one part of a circuit to another.
Wires joined		A 'blob' should be drawn where wires are connected (joined), but it is sometimes omitted. Wires connected at 'crossroads' should be staggered slightly to form two T-junctions, as shown on the right.
Wires not joined		In complex diagrams it is often necessary to draw wires crossing even though they are not connected. I prefer the 'bridge' symbol shown on the right because the simple crossing on the left may be misread as a join where you have forgotten to add a 'blob'!

Power Supplies

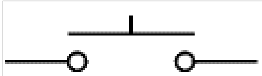
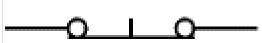
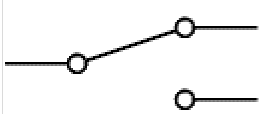
Component	Circuit Symbol	Function of Component
Cell		Supplies electrical energy. The larger terminal (on the left) is positive (+). A single cell is often called a battery, but strictly a battery is two or more cells joined together.
Battery		Supplies electrical energy. A battery is more than one cell. The larger terminal (on the left) is positive (+).
DC supply		Supplies electrical energy. DC = Direct Current, always flowing in one direction.
AC supply		Supplies electrical energy. AC = Alternating Current, continually changing direction.
Fuse		A safety device which will 'blow' (melt) if the current flowing through it exceeds a specified value.
Transformer		Two coils of wire linked by an iron core. Transformers are used to step up (increase) and step down (decrease) AC voltages. Energy is transferred between the coils by the magnetic field in the core. There is no electrical connection between the coils.

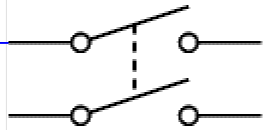
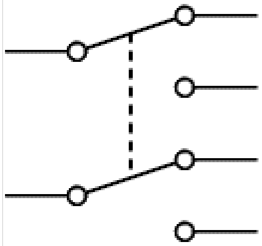
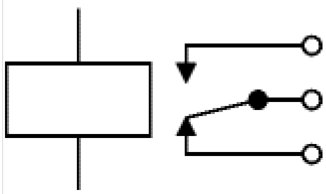
Earth (Ground)		A connection to earth. For many electronic circuits this is the 0V (zero volts) of the power supply, but for mains electricity and some radio circuits it really means the earth. It is also known as ground.

Output Devices: Lamps, Heater, Motor, etc.

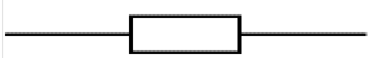
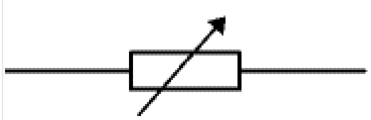
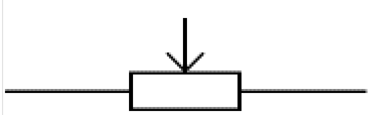
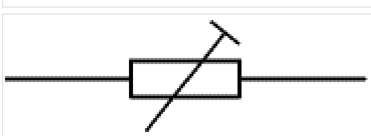
Component	Circuit Symbol	Function of Component
Lamp (lighting)		A transducer which converts electrical energy to light. This symbol is used for a lamp providing illumination, for example a car headlamp or torch bulb.
Lamp (indicator)		A transducer which converts electrical energy to light. This symbol is used for a lamp which is an indicator, for example a warning light on a car dashboard.
Heater		A transducer which converts electrical energy to heat.
Motor		A transducer which converts electrical energy to kinetic energy (motion).
Bell		A transducer which converts electrical energy to sound.
Buzzer		A transducer which converts electrical energy to sound.
Inductor (Coil, Solenoid)		A coil of wire which creates a magnetic field when current passes through it. It may have an iron core inside the coil. It can be used as a transducer converting electrical energy to mechanical energy by pulling on something.

Switches

Component	Circuit Symbol	Function of Component
Push Switch (push-to-make)		A push switch allows current to flow only when the button is pressed. This is the switch used to operate a doorbell.
Push-to-Break Switch		This type of push switch is normally closed (on), it is open (off) only when the button is pressed.
On-Off Switch (SPST)		SPST = Single Pole, Single Throw. An on-off switch allows current to flow only when it is in the closed (on) position.
2-way Switch (SPDT)		SPDT = Single Pole, Double Throw. A 2-way changeover switch directs the flow of current to one of two routes according to its position. Some SPDT switches have a central off position and are described as 'on-off-on'.

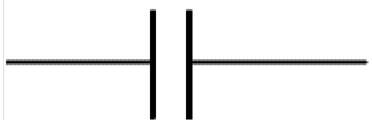
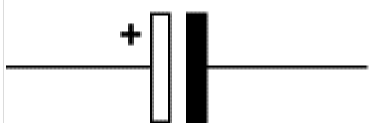
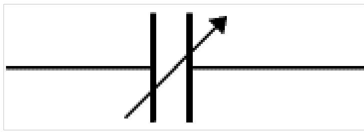
Dual On-Off Switch (DPST)		DPST = Double Pole, Single Throw. A dual on-off switch which is often used to switch mains electricity because it can isolate both the live and neutral connections.
Reversing Switch (DPDT)		DPDT = Double Pole, Double Throw. This switch can be wired up as a reversing switch for a motor. Some DPDT switches have a central off position.
Relay		An electrically operated switch, for example a 9V battery circuit connected to the coil can switch a 230V AC mains circuit. NO = Normally Open, COM = Common, NC = Normally Closed.

Resistors

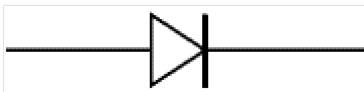
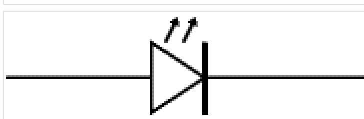
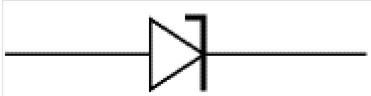
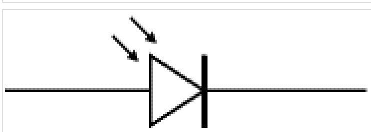
Component	Circuit Symbol	Function of Component
Resistor		A resistor restricts the flow of current, for example to limit the current passing through an LED. A resistor is used with a capacitor in a timing circuit. Some publications still use the old resistor symbol: 
Variable Resistor (Rheostat)		This type of variable resistor with 2 contacts (a rheostat) is usually used to control current. Examples include: adjusting lamp brightness, adjusting motor speed, and adjusting the rate of flow of charge into a capacitor in a timing circuit.
Variable Resistor (Potentiometer)		This type of variable resistor with 3 contacts (a potentiometer) is usually used to control voltage. It can be used like this as a transducer converting position (angle of the control spindle) to an electrical signal.
Variable Resistor (Preset)		This type of variable resistor (a preset) is operated with a small screwdriver or similar tool. It is designed to be set when the circuit is made and then left without further adjustment. Presets are cheaper

		than normal variable resistors so they are often used in projects to reduce the cost.

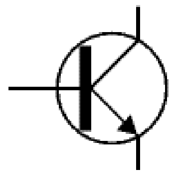
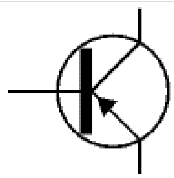
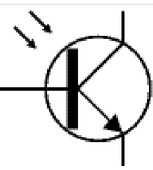
Capacitors

Component	Circuit Symbol	Function of Component
Capacitor		A capacitor stores electric charge. A capacitor is used with a resistor in a timing circuit. It can also be used as a filter, to block DC signals but pass AC signals.
Capacitor, polarised		A capacitor stores electric charge. This type must be connected the correct way round. A capacitor is used with a resistor in a timing circuit. It can also be used as a filter, to block DC signals but pass AC signals.
Variable Capacitor		A variable capacitor is used in a radio tuner.
Trimmer Capacitor		This type of variable capacitor (a trimmer) is operated with a small screwdriver or similar tool. It is designed to be set when the circuit is made and then left without further adjustment.

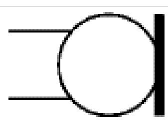
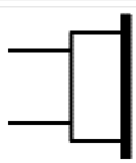
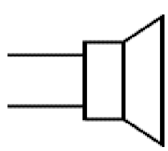
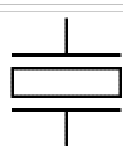
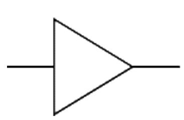
Diodes

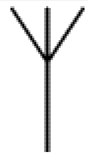
Component	Circuit Symbol	Function of Component
Diode		A device which only allows current to flow in one direction.
LED Light Emitting Diode		A transducer which converts electrical energy to light.
Zener Diode		A special diode which is used to maintain a fixed voltage across its terminals.
Photodiode		A light-sensitive diode.

Transistors

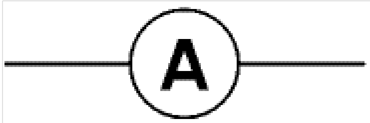
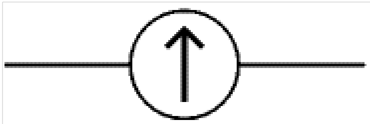
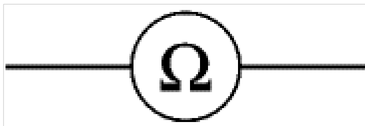
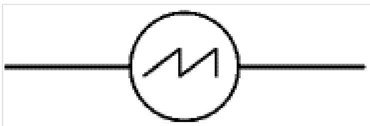
Component	Circuit Symbol	Function of Component
Transistor NPN		A transistor amplifies current. It can be used with other components to make an amplifier or switching circuit.
Transistor PNP		A transistor amplifies current. It can be used with other components to make an amplifier or switching circuit.
Phototransistor		A light-sensitive transistor.

Audio and Radio Devices

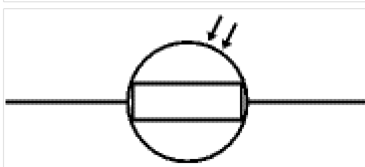
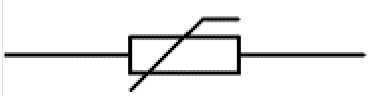
Component	Circuit Symbol	Function of Component
Microphone		A transducer which converts sound to electrical energy.
Earphone		A transducer which converts electrical energy to sound.
Loudspeaker		A transducer which converts electrical energy to sound.
Piezo Transducer		A transducer which converts electrical energy to sound.
Amplifier (general symbol)		An amplifier circuit with one input. Really it is a block diagram symbol because it represents a circuit rather than just one component.

Aerial (Antenna)		A device which is designed to receive or transmit radio signals. It is also known as an antenna.

Meters and Oscilloscope

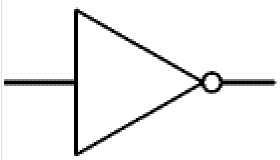
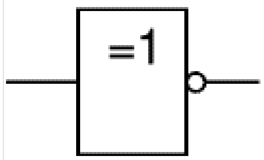
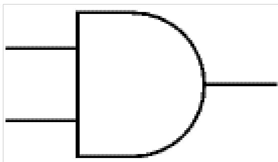
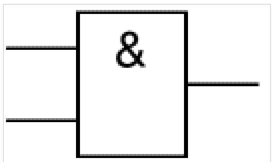
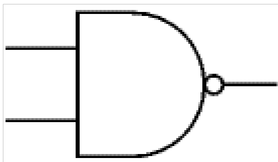
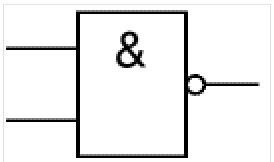
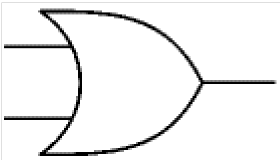
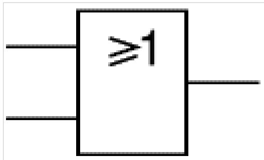
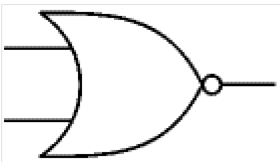
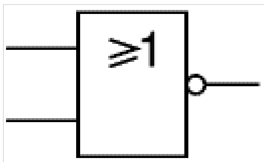
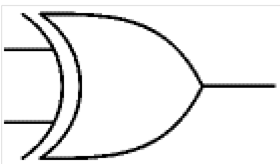
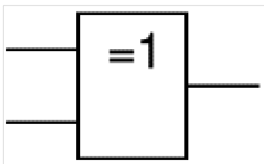
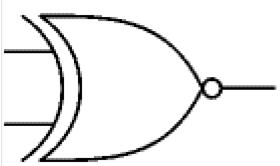
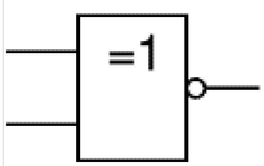
Component	Circuit Symbol	Function of Component
Voltmeter		A voltmeter is used to measure voltage. The proper name for voltage is 'potential difference', but most people prefer to say voltage!
Ammeter		An ammeter is used to measure current.
Galvanometer		A galvanometer is a very sensitive meter which is used to measure tiny currents, usually 1mA or less.
Ohmmeter		An ohmmeter is used to measure resistance. Most multimeters have an ohmmeter setting.
Oscilloscope		An oscilloscope is used to display the shape of electrical signals and it can be used to measure their voltage and time period.

Sensors (input devices)

Component	Circuit Symbol	Function of Component
LDR		A transducer which converts brightness (light) to resistance (an electrical property). LDR = Light Dependent Resistor
Thermistor		A transducer which converts temperature (heat) to resistance (an electrical property).

Logic Gates

Logic gates process signals which represent **true** (1, high, +Vs, on) or **false** (0, low, 0V, off). For more information please see the Logic Gates page.
There are two sets of symbols: traditional and IEC (International Electrotechnical Commission).

Gate Type	Traditional Symbol	IEC Symbol	Function of Gate
NOT			A NOT gate can only have one input. The 'o' on the output means 'not'. The output of a NOT gate is the inverse (opposite) of its input, so the output is true when the input is false. A NOT gate is also called an inverter.
AND			An AND gate can have two or more inputs. The output of an AND gate is true when all its inputs are true.
NAND			A NAND gate can have two or more inputs. The 'o' on the output means 'not' showing that it is a Not AND gate. The output of a NAND gate is true unless all its inputs are true.
OR			An OR gate can have two or more inputs. The output of an OR gate is true when at least one of its inputs is true.
NOR			A NOR gate can have two or more inputs. The 'o' on the output means 'not' showing that it is a Not OR gate. The output of a NOR gate is true when none of its inputs are true.
EX-OR			An EX-OR gate can only have two inputs. The output of an EX-OR gate is true when its inputs are different (one true, one false).
EX-NOR			An EX-NOR gate can only have two inputs. The 'o' on the output means 'not' showing that it is a Not EX-OR gate. The output of an EX-NOR gate is true when its inputs are the same (both true or both false).

Multimeters

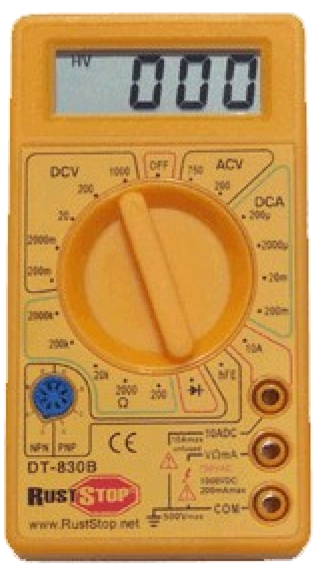
Multimeters are very useful test instruments. By operating a multi-position switch on the meter they can be quickly and easily set to be a voltmeter, an ammeter or an ohmmeter. They have several settings (called 'ranges') for each type of meter and the choice of AC or DC. Some multimeters have additional features such as transistor testing and ranges for measuring capacitance and frequency.

Choosing a multimeter

The photographs below show modestly priced multimeters which are suitable for general electronics use, you should be able to buy meters like these for less than £15. A digital multimeter is the best choice for your first multimeter; even the cheapest will be suitable for testing simple projects.

If you are buying an analogue multimeter make sure it has a high sensitivity of 20k/V or greater on DC voltage ranges, anything less is not suitable for electronics. The sensitivity is normally marked in a corner of the scale, ignore the lower AC value (sensitivity on AC ranges is less important), the higher DC value is the critical one. Beware of cheap analogue multimeters sold for electrical work on cars because their sensitivity is likely to be too low.

Digital multimeters



All digital meters contain a battery to power the display so they use virtually no power from the circuit under test. This means that on their DC voltage ranges they have a very high resistance (usually called input impedance) of 1M or more, usually 10M, and they are very unlikely to affect the circuit under test.

Typical ranges for digital multimeters like the one illustrated:

(The values given are the maximum reading on each range)

DC Voltage: 200mV, 2000mV, 20V, 200V, 600V.

AC Voltage: 200V, 600V.

DC Current: 200µA, 2000µA, 20mA, 200mA, 10A*.

*The 10A range is usually unfused and connected via a special socket.

AC Current: None. (You are unlikely to need to measure this).

Resistance: 200 ohms, 2000 ohms, 20k ohms, 200k ohms, 2000k ohms, Diode Test.

Digital meters have a special diode test setting because their resistance ranges cannot be used to test diodes and other semiconductors.

Analogue multimeters

Analogue meters take a little power from the circuit under test to operate their pointer. They must have a high sensitivity of at least 20k/V or they may upset the circuit under test and give an incorrect reading. See the section below on sensitivity for more details.

Batteries inside the meter provide power for the resistance ranges, they will last several years but you should avoid leaving the meter set to a resistance range in case the leads touch accidentally and run the battery flat.

Typical ranges for analogue multimeters like the one illustrated:

(The voltage and current values given are the maximum reading on each range)

DC Voltage: 0.5V, 2.5V, 10V, 50V, 250V, 1000V.

AC Voltage: 10V, 50V, 250V, 1000V.

DC Current: 50µA, 2.5mA, 25mA, 250mA.

A high current range is often missing from this type of meter.

AC Current: None. (You are unlikely to need to measure this).

Resistance: 20 ohms, 200 ohms, 2k ohms, 20k ohms, 200k ohms.

These resistance values are in the middle of the scale for each range.

It is a good idea to leave an analogue multimeter set to a DC voltage range such as 10V when not in use. It is less likely to be damaged by careless use on this range, and there is a good chance that it will be the range you need to use next anyway!

Sensitivity of an analogue multimeter

Multimeters must have a high sensitivity of at least 20k/V otherwise their resistance on DC voltage ranges may be too low to avoid upsetting the circuit under test and giving an incorrect reading. To obtain valid readings the meter resistance should be at least 10 times the circuit resistance (take this to be the highest resistor value near where the meter is connected). You can increase the meter resistance by selecting a higher voltage range, but this may give a reading which is too small to read accurately!

On any DC voltage range:

Analogue Meter Resistance = Sensitivity × Max. reading of range

e.g. a meter with 20k/V sensitivity on its 10V range has a resistance of 20k/V × 10V = 200k.

By contrast, digital multimeters have a constant resistance of at least 1M ohms (often 10M ohms) on all their DC voltage ranges. This is more than enough for almost all circuits.

RESISTORS

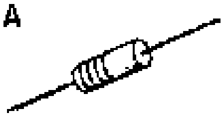
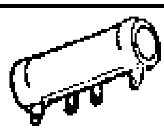
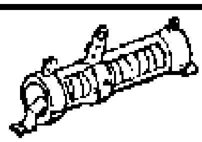
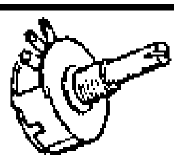
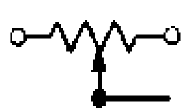
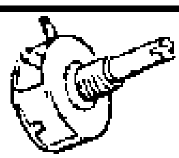
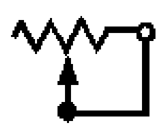
A **Resistor** is a two-terminal electronic component designed to oppose an electric current by producing a voltage drop between its terminals in proportion to the current, that is, in accordance with Ohm's law:

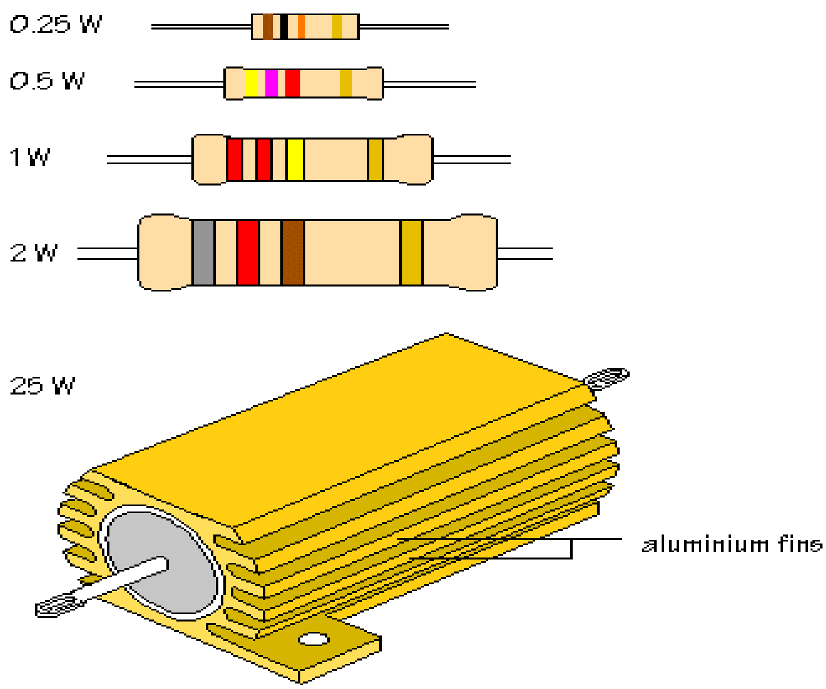
$$V = IR$$

Resistors are used as part of electrical networks and electronic circuits. They are extremely commonplace in most electronic equipment. Practical resistors can be made of various compounds and films, as well as resistance wire (wire made of a high-resistivity alloy, such as nickel/chrome).

The primary characteristics of resistors are their resistance and the power they can dissipate. Other characteristics include temperature coefficient, noise, and inductance. Less well-known is critical resistance, the value below which power dissipation limits the maximum permitted current flow, and above which the limit is applied voltage. Critical resistance depends upon the materials constituting the resistor as well as its physical dimensions; it's determined by design.

Resistors can be integrated into hybrid and printed circuits, as well as integrated circuits. Size, and position of leads (or terminals) are relevant to equipment designers; resistors must be physically large enough not to overheat when dissipating their power.

TYPICAL RESISTOR	TYPE	SYMBOL
A 	FIXED CARBON	
B 	FIXED WIREWOUND (TAPPED)	
C 	ADJUSTABLE WIREWOUND	
D 	POTENTIOMETER	
E 	RHEOSTAT	



Units

The **ohm** (symbol: Ω) is a SI-driven unit of electrical resistance, named after Georg Simon Ohm. Commonly used multiples and submultiples in electrical and electronic usage are the milliohm, kilohm, and megohm.

Examples	
R47	0.47 ohms
4R7	4.7 ohms
470R	470 ohms
4K7	4.7K ohms
47K	47K ohms
47K3	47.3K ohms

470K	470K ohms
4M7	4.7M ohms

The unit of Resistor is **"OHMS".**

Sub Unit:

nΩ = Nano OHMS = 10^{-9} = 1/1000000000
µΩ = Micro OHMS = 10^{-6} = 1-1000000
mΩ = Milli OHMS = 10^{-3} = 1/1000
A = OHMS = 1
KΩ = Kilo OHMS = 10^{3} = 1000
MΩ = Mega OHMS = 10^{6} = 1000000
GΩ = Giga OHMS = 10^{9} = 1000000000

Resistor Conversion:

1000 nΩ = 1 µΩ

1000 µ Ω = 1 mΩ

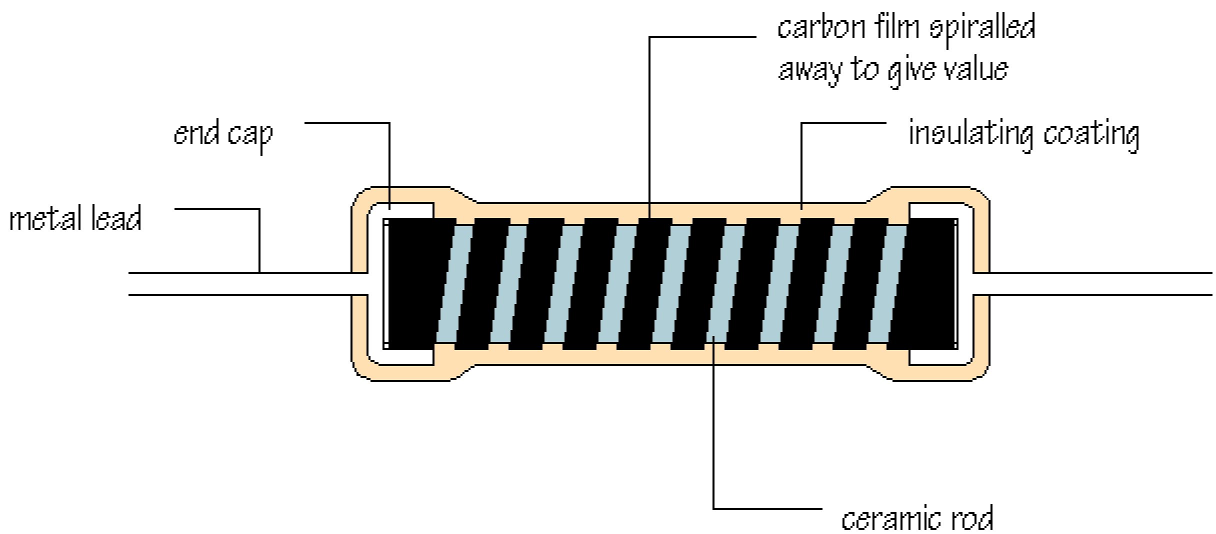
1000 mΩ = 1 Ω

1000 Ω = 1 KΩ

1000 KΩ = 1 MΩ

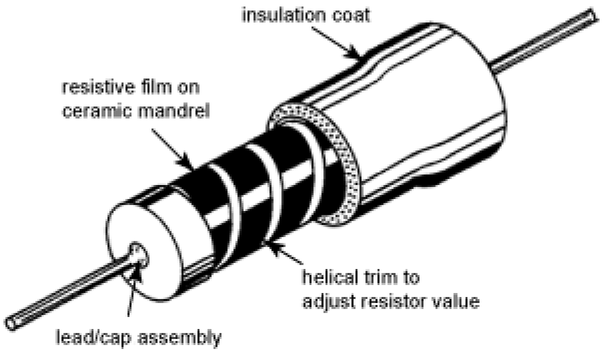
1000 MΩ = 1 GΩ

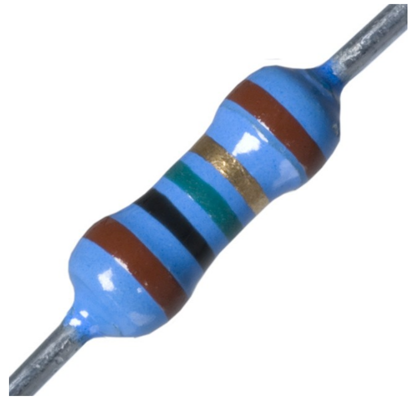
Carbon film



A carbon film is deposited on an insulating substrate, and a helix cut in it to create a long, narrow resistive path. Varying shapes, coupled with the resistivity of carbon, (ranging from 9 to 40 µΩ-cm) can provide a variety of resistances.[1] Carbon film resistors feature a power rating range of 1/6 W to 5 W at 70°C. Resistances available range from 1 ohm to 10 megohm. The carbon film resistor can operate between temperatures of -55°C to 155°C. It has 200 to 600 volts maximum working voltage range

Metal film





A common type of axial resistor today is referred to as a metal-film resistor. MELF (Metal Electrode Leadless Face) resistors often use the same technology, but are a cylindrically shaped resistor designed for surface mounting. [Note that other types of resistors, e.g. carbon composition, are also available in "MELF" packages].

Metal film resistors are usually coated with nickel chromium (NiCr), but might be coated with any of the cermet materials listed above for thin film resistors. Unlike thin film resistors, the material may be applied using different techniques than sputtering (though that is one such technique). Also, unlike thin-film resistors, the resistance value is determined by cutting a helix through the coating rather than by etching. [This is similar to the way carbon resistors are made.] The result is a reasonable tolerance (0.5, 1, or 2%) and a temperature coefficient of (usually) 25 or 50 ppm/K.

Wire wound

Wire wound resistors are commonly made by winding a metal wire around a ceramic, plastic, or fiberglass core. The ends of the wire are soldered or welded to two caps, attached to the ends of the core. The assembly is protected with a layer of paint, molded plastic, or an enamel coating baked at high temperature. The wire leads are usually between 0.6 and 0.8 mm in diameter and tinned for ease of soldering. For higher power wire wound resistors, either a ceramic outer case or an aluminum outer case on top of an insulating layer is used. The aluminum-cased types are designed to be attached to a heat sink to dissipate the heat; the rated power is dependent on being used with a suitable heat sink, e.g., a 50 W power rated resistor will overheat at around one fifth of the power dissipation if not used with a heat sink.

Actual lengths will vary

Because wire wound resistors are coils they have more undesirable inductance than other types of resistor, although winding the wire in sections with alternately reversed direction can minimize inductance.

Cermet

A **cer met** is a composite material composed of ceramic (cer) and metallic (met) materials. A cer met is ideally designed to have the optimal properties of both a ceramic, such as high temperature resistance and hardness, and those of a metal, such as the ability to undergo plastic deformation. The metal is used as a binder for an oxide, boride, carbide, or alumina. Generally, the metallic elements used are nickel, molybdenum, and cobalt. Depending on the physical structure of the material, cermets can also be metal matrix composites, but cermets are usually less than 20% metal by volume.

Cermets are used in the manufacture of resistors (especially potentiometers), capacitors, and other electronic components which may experience high temperatures.

Cermets are being used instead of tungsten carbide in saws and other brazed tools due to their superior wear and corrosion properties. TiCN, TiC, TiN and similar can be brazed like tungsten carbide if properly prepared however they require special handling during grinding.

More complex materials, known as Cermet 2 or Cermet II, are being utilized since they give considerably longer life in cutting tools while both brazing and grinding like tungsten carbide.

Some types of cermets are also being considered for use as spacecraft shielding as they resist the high velocity impacts of micrometeoroids and orbital debris much more effectively than more traditional spacecraft materials such as aluminum and other metals.

Measurement

Nearly always, the resistance value is of interest. The value of a resistor can be measured with an ohmmeter, which may be one function of a multimeter. Usually, probes on the ends of test leads connect to the resistor.

Measuring low-value resistors, such as fractional-ohm resistors, with acceptable accuracy requires four-terminal connections. One pair of terminals applies a known, calibrated current to the resistor, while the other pair senses the voltage drop across the resistor. Some laboratory test instruments have spring-loaded pairs of contacts, with neighboring contacts electrically isolated from each other. Better digital multimeters have four terminals on their panels, generally used with special test leads. These comprise four wires in all, and have special test clips with jaws insulated from each other. One jaw provides the measuring current, while the other senses the voltage drop.

Series and parallel resistors

Main article: Series and parallel circuits

Resistors in a parallel configuration each have the same potential difference (voltage). To find their total equivalent resistance (R_{eq}):

$$1/R = 1/R1 + 1/R2 + \ldots.. + 1/Rn$$

The parallel property can be represented in equations by two vertical lines "||" (as in geometry) to simplify equations. For two resistors,

$R = R1 // R2 = R1,R2 / R1 + R2$

The current through resistors in series stays the same, but the voltage across each resistor can be different. The sum of the potential differences (voltage) is equal to the total voltage. To find their total resistance:

$$R = R1 + R2 \ldots..+ Rn$$

A resistor network that is a combination of parallel and series can sometimes be broken up into smaller parts that are either one or the other. For instance,

However, many resistor networks cannot be split up in this way. Consider a cube, each edge of which has been replaced by a resistor. For example, determining the resistance between two opposite vertices requires matrix methods for the general case. However, if all twelve resistors are equal, the corner-to-corner resistance is ⅚ of any one of them.

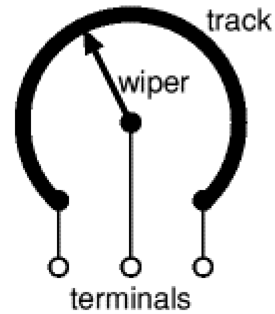
The practical application to resistors is that a resistance of any non-standard value can be obtained by connecting standard values in series or in parallel.

Fixed and Variable Resistors

There are two kinds of resistors, FIXED and VARIABLE. The fixed resistor will have one value and will never change (other than through temperature, age, etc.). The resistors shown in A and B of figure 1-29are classed as fixed resistors. The tapped resistor illustrated in B has several fixed taps and makes more than one resistance value available. The sliding contact resistor shown in C has an adjustable collar that can be moved to tap off any resistance within the ohmic value range of the resistor.

There are two types of variable resistors, one called a POTENTIOMETER and the other a RHEOSTAT (see views D and E of fig. 1-29.)An example of the potentiometer is the volume control on your radio, and an example of the rheostat is the dimmer control for the dash lights in an automobile. There is a slight difference between them. Rheostats usually have two connections, one fixed and the other moveable. Any variable resistor can properly be called a rheostat. The potentiometer always has three connections, two fixed and one moveable. Generally, the rheostat has a limited range of values and

a high current-handling capability. The potentiometer has a wide range of values, but it usually has a limited current-handling capability. Potentiometers are always connected as voltage dividers.



Construction

Variable resistors consist of a resistance **track** with connections at both ends and a **wiper** which moves along the track as you turn the spindle. The track may be made from carbon, cer met (ceramic and metal mixture) or a coil of wire (for low resistances). The track is usually rotary but straight track versions, usually called sliders, are also available.

Standard Variable Resistor

Variable resistors may be used as a rheostat with **two** connections (the wiper and just one end of the track) or as a potentiometer with all **three** connections in use. Miniature versions called presets are made for setting up circuits which will not require further adjustment.

Variable resistors are often called **potentiometers** in books and catalogues. They are specified by their maximum resistance, linear or logarithmic track, and their physical size. The standard spindle diameter is 6mm.

The resistance and type of track are marked on the body:

4K7 LIN means 4.7 kΩ linear track.

1M LOG means 1 MΩ logarithmic track.

Some variable resistors are designed to be mounted directly on the circuit board, but most are for mounting through a hole drilled in the case containing the circuit with stranded wire connecting their terminals to the circuit board.

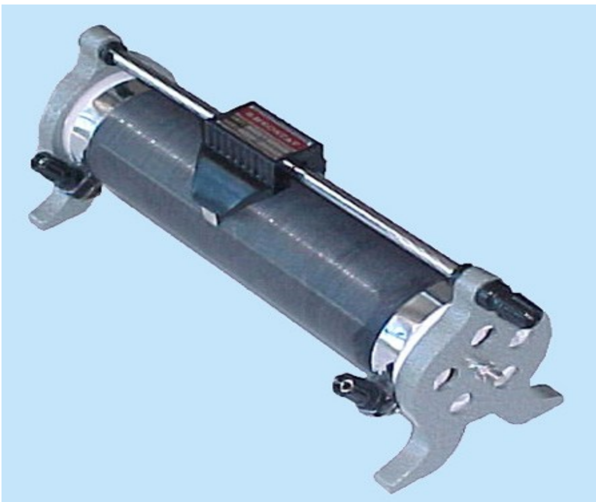
Linear (LIN) and Logarithmic (LOG) tracks

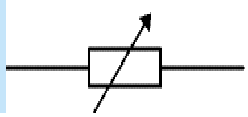
Linear (LIN) track means that the resistance changes at a constant rate as you move the wiper. This is the standard arrangement and you should assume this type is required if a project does not specify the type of track. Presets always have linear tracks.

Logarithmic (LOG) track means that the resistance changes slowly at one end of the track and rapidly at the other end, so halfway along the track is **not** half the total resistance! This arrangement is used for volume (loudness) controls because the human ear has a logarithmic response to loudness so fine control (slow change) is required at low volumes and coarser

control (rapid change) at high volumes. It is important to connect the ends of the track the correct way round, if you find that turning the spindle increases the volume rapidly followed by little further change you should swap the connections to the ends of the track.

Rheostat



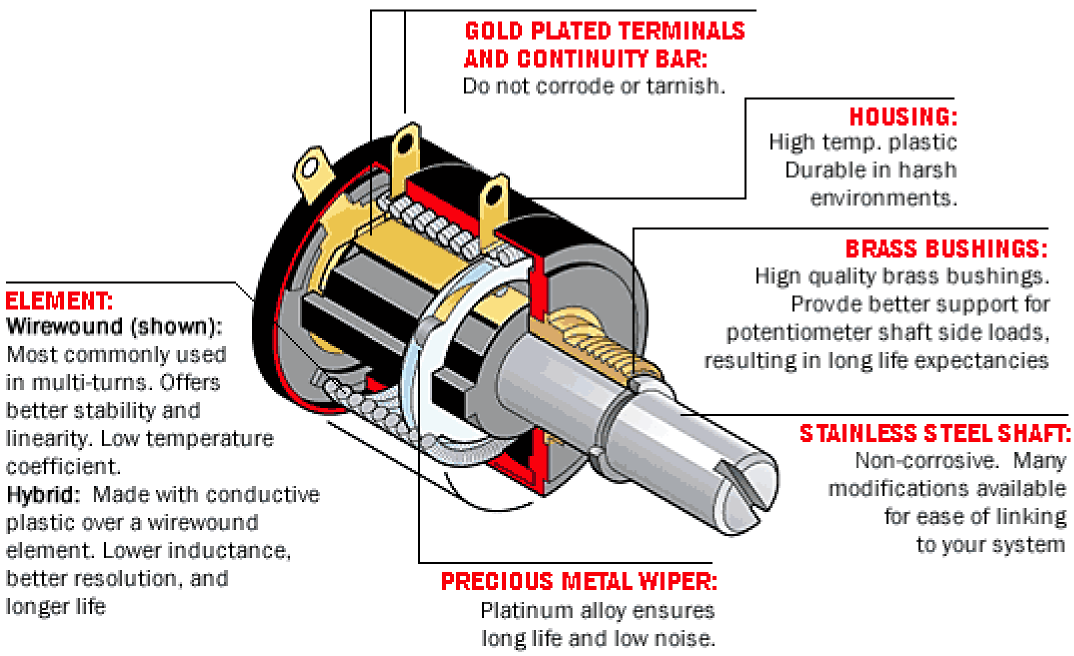


This is the simplest way of using a variable resistor. **Two terminals** are used: one connected to an end of the track, the other to the moveable wiper. Turning the spindle changes the resistance between the two terminals from zero up to the maximum resistance.

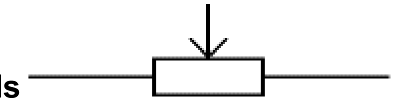
Rheostats are often used to **vary current**, for example to control the brightness of a lamp or the rate at which a capacitor charges.

If the rheostat is mounted on a printed circuit board you may find that all three terminals are connected! However, one of them will be linked to the wiper terminal. This improves the mechanical strength of the mounting but it serves no function electrically.

Potentiometer



Variable resistors used as potentiometers have all **three terminals** connected.



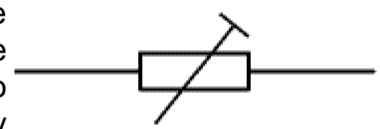
Potentiometer Symbol

This arrangement is normally used to **vary voltage**, for example to set the switching point of a circuit with a sensor, or control the volume (loudness) in an amplifier circuit. If the terminals at the ends of the track are connected across the power supply

then the wiper terminal will provide a voltage which can be varied from zero up to the maximum of the supply.

Presets

These are miniature versions of the standard variable resistor. They are designed to be mounted directly onto the circuit board and adjusted only when the circuit is built. For example to set the frequency of an alarm tone or the sensitivity of a light-sensitive circuit. A small screwdriver or similar tool is required to adjust presets.



Preset Symbol

Presets are much cheaper than standard variable resistors so they are sometimes used in projects where a standard variable resistor would normally be used.

Multiturn presets are used where very precise adjustments must be made. The screw must be turned many times (10+) to move the slider from one end of the track to the other, giving very fine control.

Preset
(open style)

Presets
(closed style)

Multiturn preset

Four-band resistors

Main article: Electronic color code

Four-band identification is the most commonly used color-coding scheme on all resistors. It consists of four colored bands that are painted around the body of the resistor. The first two bands encode the first two significant digits of the resistance value, the third is a power-of-ten multiplier or number-of-zeroes, and the fourth is the tolerance accuracy, or acceptable error, of the value. Sometimes a fifth band identifies the thermal coefficient, but this must be distinguished from the true 5-color system, with 3 significant digits.

For example, green-blue-yellow-red is $56 \times 10^4\ \Omega = 560\ \text{k}\Omega \pm 2\%$. An easier description can be as followed: the first band, green, has a value of 5 and the second band, blue, has a value of 6, and is counted as 56. The third band, yellow, has a value of 10^4, which adds four 0's to the end, creating 560,000Ω at ±2% tolerance accuracy. 560,000Ω changes to 560 kΩ ±2% (as a kilo- is 10^3).

Each color corresponds to a certain digit, progressing from darker to lighter colors, as shown in the chart below.

5 band axial resistors

5-band identification is used for higher precision (lower tolerance) resistors (1%, 0.5%, 0.25%, 0.1%), to specify a third significant digit. The first three bands represent the significant digits, the fourth is the multiplier, and the fifth is the tolerance. Five-band resistors with a gold or silver 4th band are sometimes encountered, generally on older or specialized resistors. The 4th band is the tolerance and the 5th the temperature coefficient.

IV Band Colour Coding of Resistor

V Band Colour Coding of Resistor

Color	1^{st} band	2^{nd} band	3^{rd} band	4^{th} band (multiplier)	5^{th} band (tolerance)	Temp. Coefficient
Black	_	0	0	_	_	
Brown	1	1	1	0	±1% (F)	100 ppm
Red	2	2	2	00	±2% (G)	50 ppm
Orange	3	3	3	000	_	15 ppm
Yellow	4	4	4	0000	_	25 ppm
Green	5	5	5	00000	_	
Blue	6	6	6	000000	_	
Violet	7	7	7	0000000	_	
Gray	8	8	8	00000000	_	
White	9	9	9	000000000	_	
Gold	_	_	_	×1/10	±5% (J)	
Silver	_	_	_	×1/100	±10% (K)	
No Band	_	_	_		±20% (M)	

Thermistor

A **thermistor** is a type of resistor whose resistance varies with temperature. The word is a portmanteau of *thermal* and *resistor*. Thermistors are widely used as inrush current limiters, temperature sensors, self-resetting over current protectors, and self-regulating heating elements.

Thermistors differ from resistance temperature detectors (RTD) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a higher precision within a limited temperature range.

PTC thermistors

PTC thermistors for over current protection

Ceramic PTC thermistors are used instead of conventional fuses to protect loads such as motors, transformers, etc. or electronic circuits against over current. They not only respond to inadmissibly high currents but also if a preset temperature limit is exceeded. Thermistor fuses limit the power dissipation of the overall circuit by increasing their resistance and thus reducing the current to a harmless residual value. In contrast to conventional fuses, they do not have to be replaced after elimination of the fault but resume their protective function immediately after a short cooling-downtime.

As opposed to PTC thermistors made of plastic materials, ceramic PTC thermistors always return to their initial resistance value, even after frequent heating/cooling cycles.

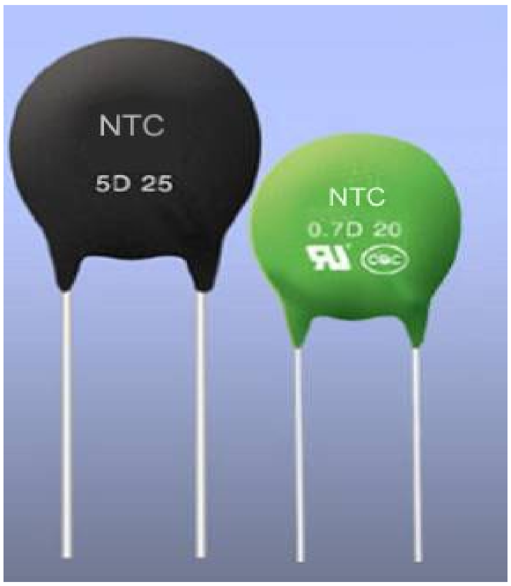
PTC thermistors as limit temperature sensors

With PTC thermistors as temperature sensors only the steep region of the *R/T* characteristic is Used. The resistance of the PTC thermistor is to be regarded as a function of the ambient temperature [*R*PTC = f (*T*A)].
The precondition for this relationship between resistance and ambient temperature is that self-heating and/or the varistor effect are excluded. This means that these PTC thermistors must be operated in the lowest possible field strengths. To enable a fast response, thermistor sensors have especially small dimensions. High control accuracy is achieved by using materials with an extra steep resistance/temperature characteristic.

Limit temperature measurement for industrial applications

A PTC thermistor can be used effectively to detect whether a temperature limit in industrial equipment, liquids, etc. is exceeded. The PTC thermistor is mounted in thermal contact with the medium that has to be protected from overheating. When the rated temperature limit of the medium is reached, the resistance of the PTC thermistor increases abruptly. In connection with a control unit, this signal can be used to automatically switch off the power supply of a load. EPCOS offers leaded disks, metal tags, screw-type metal cases as well as surface-mounted devices.

NTC thermistors



1. Introduction
An NTC thermistor has to be connected in series to the power source circuit to avoid the surge current at the instant when the electronic circuits are turned on. The device can effectively suppress the surge current, and its resistance and power consumption can be greatly reduced after that through the continuous effect of the current so as not to affect the normal work current. Therefore the Power NTC thermistor is the most convenient and efficient instrument to curb the surge current and protect the electronic devices from being damaged.

2. Applications
Applicable to the protection of the power circuits of conversion power supply, switching power supply, UPS power supply, electric heaters, electronic energy-saving lamps, electronic ballasts and other electronic devices, and the filament protection of color picture tubes, incandescent lamps and other lights.

3. Characteristics:
¡¤Small size, Strong power and strong capability of surge current protection.
¡¤Characteristics Fast response to the rapidly surge.
¡¤Big material constant (B value), Small remain resistance.
¡¤Longevity of service, High reliability.
¡¤Integral series, Extensive operating range.

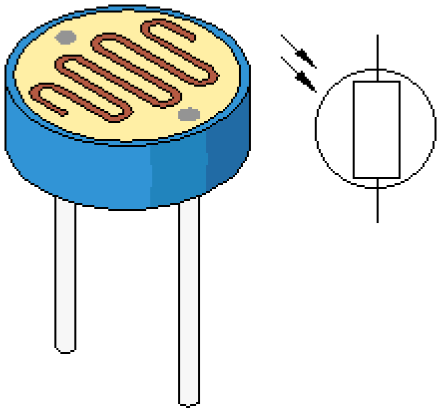
Varistor

Avaristor is an electronic component with a significant non-ohmic current–voltage characteristic. The name is a portmanteau of *variable resistor*. Varistors are often used to protect circuits against excessive transient voltages by incorporating them into the circuit in such a way that, when triggered, they will shunt the current created by the high voltage away from the sensitive components. A varistor is also known as *Voltage Dependent Resistor* or **VDR**. A varistor's function is to conduct significantly increased current when voltage is excessive.

*Note: only non-ohmic variable resistors are usually called varistors. Other, ohmic types of variable resistor include the potentiometer and the rheostat.

Light Dependent Resistor

A **Light Dependent Resistor** (aka LDR, photoconductor, or photocell) is a device which has a resistance which varies according to the amount of light falling on its surface.



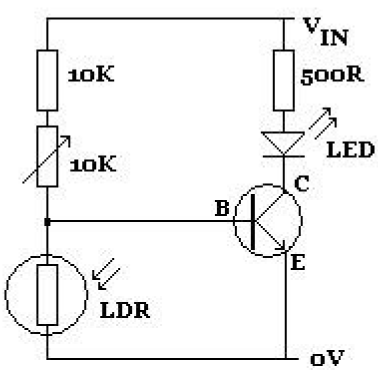
A typical light dependent resistor is pictured above together with (on the right hand side) its circuit diagram symbol. Different LDR's have different specifications, however the **LDR**'s we sell (1) in the REUK Shop (2) are fairly standard and have a resistance in total darkness of 1 MOhm, and a resistance of a couple of kOhm in bright light (*10-20kOhm @ 10 lux, 2-4kOhm @ 100 lux*).

Uses for Light Dependent Resistors

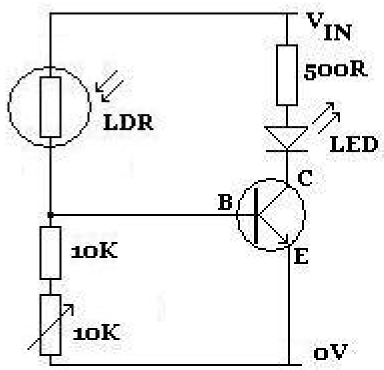
Light dependent resistors are a vital component in any electric circuit (3) which is to be turned on and off automatically according to the level of ambient light - for example, solar powered garden lights, and night security lighting.
An LDR can even be used in a simple remote control circuit using the backlight of a mobile phone to turn on a device - call the mobile from anywhere in the world, it lights up the LDR, and lighting (or a garden sprinkler (4)) can be turned on remotely!

Light Dependent Resistor Circuits

There are two basic circuits using **light dependent resistors** - the first is activated by darkness, the second is activated by light. The two circuits are very similar and just require an **LDR**, some standard resistors (5), a variable resistor (6) (aka potentiometer), and any small signal transistor (7)



In the circuit diagram above, the **LED (8) lights up** whenever the LDR is in **darkness**. The 10K variable resistor is used to fine-tune the level of darkness required before the LED lights up. The 10K standard resistor can be changed as required to achieve the desired effect, although any replacement must be at least **1K** to protect the transistor from being damaged by excessive current.



By swapping the LDR over with the 10K and 10K variable resistors (as shown above), the circuit will be activated instead by light. Whenever sufficient light falls on the LDR (manually fine-tuned using the 10K variable resistor), the LED will light up.

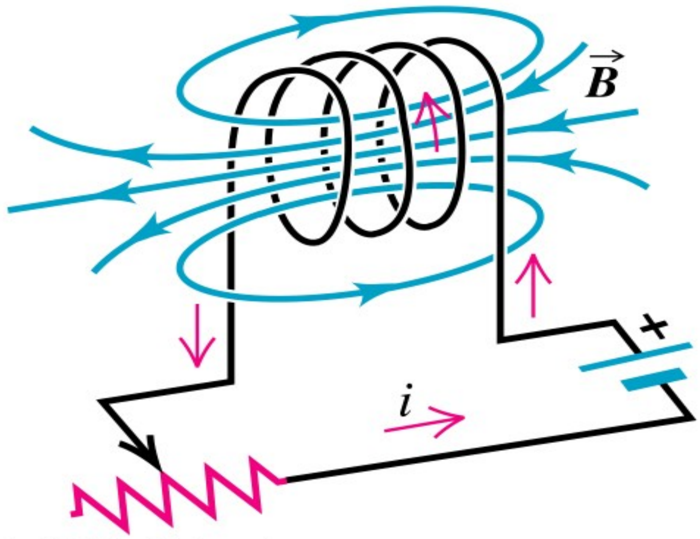
Using an LDR in the Real World

The circuits shown above are not practically useful. In a real world circuit, the LED (and resistor) between the positive voltage input (Vin) and the collector (C) of the transistor would be replaced with the device to be powered.

Typically a **relay** is used - particularly when the low voltage light detecting circuit is used to switch on (or off) a 240V mains powered device. A diagram of that part of the circuit is shown above. When darkness falls (if the LDR circuit is configured that way around), the **relay is triggered** and the 240V device - for example a security light –switches on.

NEW For details of a more advanced light/dark sensor circuit click here to read our new article **LM741 Light/Dark Sensor Circuit** We have these circuits available for sale.

Inductor



An **inductor** or **reactor** is a passive electrical component that can store energy in a magnetic field created by the electric current passing through it. An inductor's ability to store magnetic energy is measured by its inductance, in units of henries. Typically an inductor is a conducting wire shaped as a coil, the loops help create a strong magnetic field inside the coil due to Faraday's law of induction. Inductors are one of the basic electronic components used in electronics where current and voltage change with time, due to the ability of inductors to delay and reshape alternating currents.

Overview

Inductance (L) (measured in henries) is an effect resulting from the magnetic field that forms around a current-carrying conductor that tends to resist changes in the current. Electric current through the conductor creates a magnetic flux proportional to the current. A change in this current creates a change in magnetic flux that, in turn, by Faraday's law generates an electromotive force (EMF) that acts to oppose this change in current. Inductance is a measure of the amount of EMF generated for a unit change in current. For example, an inductor with an inductance of 1 henry produces an EMF of 1 volt when the current through the inductor changes at the rate of 1 ampere per second. The number of loops, the size of each loop, and the material it is wrapped around all affect the inductance. For example, the magnetic flux linking these turns can be increased by coiling the conductor around a material with a

high permeability such as iron. This can increase the inductance by 2000 times, although less so at high frequencies.

The unit of Inductor is **"Henry".**

Sub Unit:

nH	= Nano **Henry**	= 10^{-9}	= 1/1000000000
µH	= Micro **Henry**	= 10^{-6}	= 1-1000000
mH	= Milli **Henry**	= 10^{-3}	= 1/1000
H	= **Henry**	= 1	
KH	= Kilo **Henry**	= 10^{3}	= 1000

Inductor Conversion:

1000 nH = 1 µH

1000 µ H = 1 mH

1000 mH = 1 H

1000 H = 1 KH

1000 KH = 1 MH

Applications

An inductor with two 47mH windings, as may be found in a power supply.

Inductors are used extensively in analog circuits and signal processing. Inductors in conjunction with capacitors and other components form tuned circuits which can emphasize or filter out specific signal frequencies. Applications range from the use of large inductors in power supplies, which in conjunction with filter capacitors remove residual hums known as the Mains hum or other fluctuations from the direct current output, to the small inductance of the ferrite bead or torus installed around a cable to

Prevent radio frequency interference from being transmitted down the wire. Smaller inductor/capacitor combinations provide tuned circuits used in radio reception and broadcasting, for instance.

Two (or more) inductors which have coupled magnetic flux form a transformer, which is a fundamental component of every electric utility power grid. The efficiency of a transformer may decrease as the frequency increases due to eddy currents in the core material and skin effect on the windings. Size of the core can be decreased at higher frequencies and, for this reason, aircraft use 400 hertz alternating current rather than the usual 50 or 60 hertz, allowing a great saving in weight from the use of smaller transformers.

An inductor is used as the energy storage device in some switched-mode power supplies. The inductor is energized for a specific fraction of the regulator's switching frequency, and de-energized for the remainder of the cycle. This energy transfer ratio determines the input-voltage to output-voltage ratio. This X_L is used in complement with an active semiconductor device to maintain very accurate voltage control.

Inductors are also employed in electrical transmission systems, where they are used to depress voltages from lightning strikes and to limit switching currents and fault current. In this field, they are more commonly referred to as reactors.

Larger value inductors may be simulated by use of gyrator circuits.

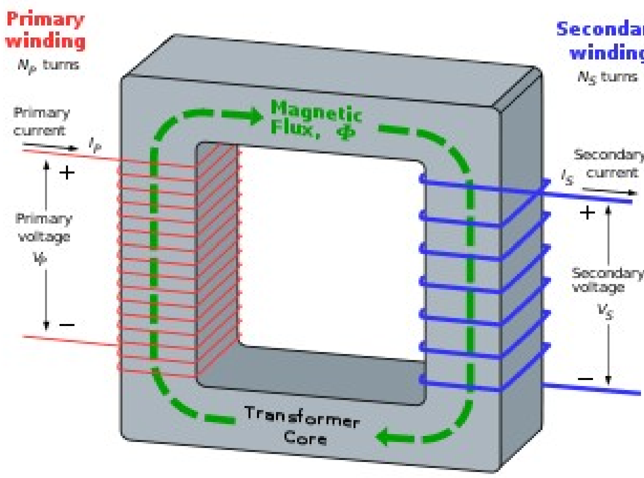
Inductor construction

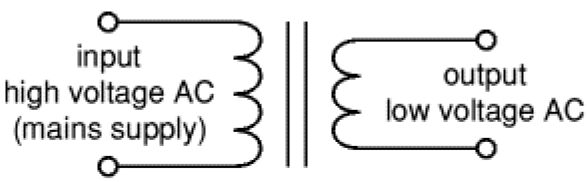
An inductor is usually constructed as a coil of conducting material, typically copper wire, wrapped around a core either of air or of ferromagnetic material. Core materials with a higher permeability than air increase the magnetic field and confine it closely to the inductor, thereby increasing the inductance. Low frequency inductors are constructed like transformers, with cores of electrical steel laminated to prevent eddy currents. 'Soft' ferrites are widely used for cores above audio frequencies, since they don't cause the large energy losses at high frequencies that ordinary iron alloys do. This is because of their narrow hysteresis curves, and their high resistivity prevents eddy currents. Inductors come in many shapes. Most are constructed as enamel coated wire wrapped around a ferrite bobbin with wire exposed on the outside, while some enclose the wire completely in ferrite and are called "shielded". Some inductors have an adjustable core, which enables changing of the inductance. Inductors used to block very high frequencies are sometimes made by stringing a ferrite cylinder or bead on a wire.

Small inductors can be etched directly onto a printed circuit board by laying out the trace in a spiral pattern. Some such planar inductors use a planar core.

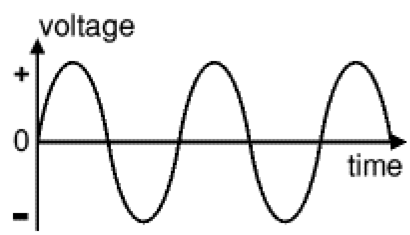
Small value inductors can also be built on integrated circuits using the same processes that are used to make transistors. Aluminum interconnect is typically used, laid out in a spiral coil pattern. However, the small dimensions limit the inductance, and it is far more common to use a circuit called a "gyrator" which uses a capacitor and active components to behave similarly to an inductor.

Transformer





Transformer



Output: low voltage AC

Transformers convert AC electricity from one voltage to another with little loss of power. Transformers work only with AC and this is one of the reasons why mains electricity is AC.

Step-up transformers increase voltage, step-down transformers reduce voltage. Most power supplies use a step-down transformer to reduce the dangerously high mains voltage (230V in UK) to a safer low voltage.

The input coil is called the **primary** and the output coil is called the **secondary**. There is no electrical connection between the two coils, instead they are linked by an alternating magnetic field created in the soft-iron core of the transformer. The two lines in the middle of the circuit symbol represent the core.

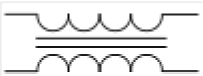
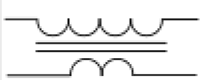
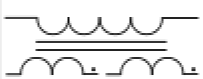
Transformers waste very little power so the power out is (almost) equal to the power in. Note that as voltage is stepped down current is stepped up.

The ratio of the number of turns on each coil, called the **turn's ratio**, determines the ratio of the voltages. A step-down transformer has a large number of turns on its primary (input) coil which is connected to the high voltage mains supply, and a small number of turns on its secondary (output) coil to give a low output voltage.

Transformer types

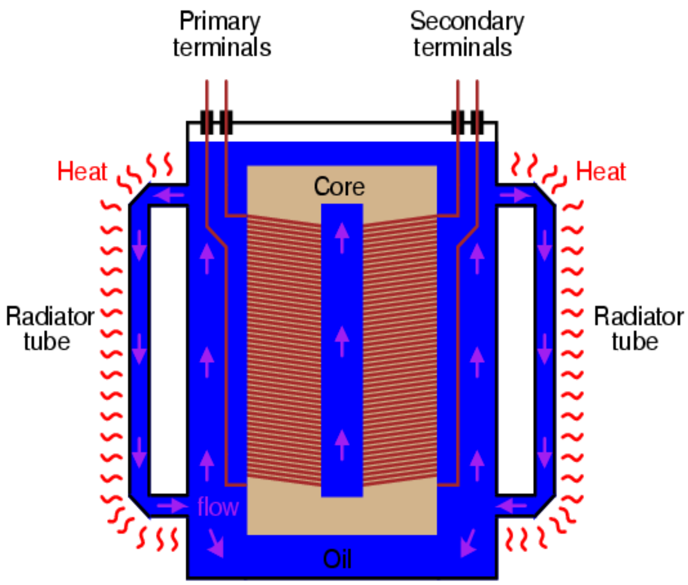
From Wikipedia, the free encyclopedia

Circuit symbols

	Transformer with two windings and iron core.
	Step-down or step-up transformer. The symbol shows which winding has more turns, but not usually the exact ratio.
	Transformer with three windings. The dots show the relative configuration of the windings.

A variety of types of electrical transformer are made for different purposes. Despite their design differences, the various types employ the same basic principle as discovered in 1831 by Michael Faraday, and share several key functional parts.

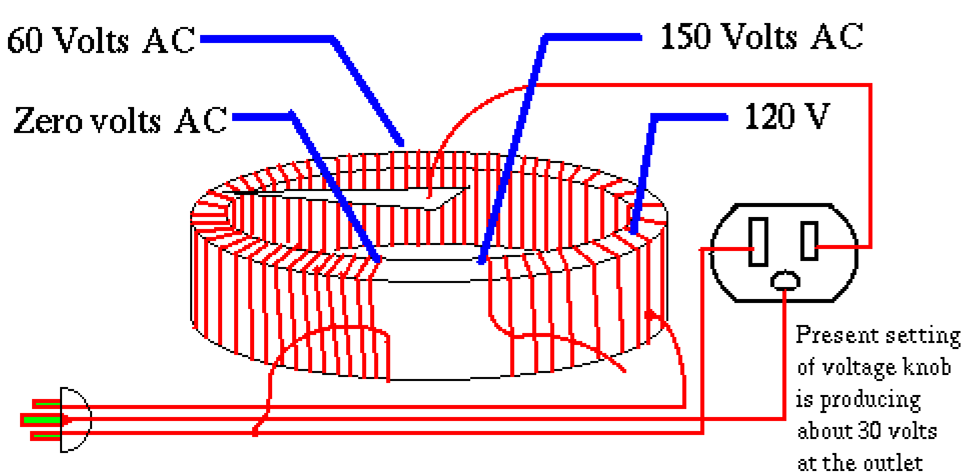
Power transformers



This is the most common type of transformer, widely used in appliances to convert mains voltage to low voltage to power electronics

- Widely available in power ratings ranging from mW to MW
- Insulated laminations minimize eddy current losses
- Small appliance and electronic transformers may use a split bobbin, giving a high level of insulation between the windings
- Rectangular core
- Core laminate stampings are usually in EI shape pairs. Other shape pairs are sometimes used.
- Mumetal shields can be fitted to reduce EMI (electromagnetic interference)
- A screen winding is occasionally used between the 2 power windings
- Small appliance and electronics transformers may have a thermal cut out built in
- Occasionally seen in low profile format for use in restricted spaces
- laminated core made with silicon steel with high permeability

Variac / Autotransformer



An autotransformer has only a single winding, which is tapped at some point along the winding. AC or pulsed voltage is applied across a portion of the winding, and a higher (or lower) voltage is produced across another portion of the same winding. While theoretically separate parts of the winding can be used for input and output, in practice the higher voltage will be connected to the ends of the winding, and the lower voltage from one end to a tap. For example, a transformer with a tap at the center of the winding can be used with 230 volts across the entire winding, and 115 volts between one end and the tap. It can be connected to a 230-volt supply to drive 115-volt equipment, or reversed to drive 230-volt equipment from 115 volts. Since the current in the

Windings is lower, the transformer is smaller, lighter cheaper and more efficient. For voltage ratios not exceeding about 3:1, an autotransformer is cheaper, lighter, smaller and more efficient than an isolating (two-winding) transformer of the same rating.

In practice, transformer losses mean that autotransformers are not perfectly reversible; one designed for stepping down a voltage will deliver slightly less voltage than required if used to step up. The difference is usually slight enough to allow reversal where the actual voltage level is not critical. This is true of isolated winding transformers too.

By exposing part of the winding coils of an autotransformer, and making the secondary connection through a sliding carbon brush, an autotransformer with a near-continuously variable turns ratio can be obtained, allowing for wide voltage adjustment in very small increments.

Constant voltage transformer (Ferro-resonance)

By arranging particular magnetic properties of a transformer core, and installing a resonant tank circuit (a capacitor and an additional winding), a transformer can be arranged to automatically keep the secondary winding voltage constant regardless (within some limits) of any variance in the primary

supply without additional circuitry or manual adjustment. CVA transformers run hotter than standard power transformers, for the regulating action is dependent on core saturation, which reduces efficiency somewhat. The output waveform features heavy distortion

Ferrite Core

Ferrite core power transformers are widely used in switched mode power supplies (SMPSUs). The powder core enables high frequency operation, and hence much smaller size to power ratio than laminated iron transformers.

Ferrite transformers are not usable as power transformers at mains frequency

Current transformers

Current transformers used in metering equipment for three-phase 400 ampere electricity supply

A current transformer (CT) is a measurement device designed to provide a current in its secondary coil proportional to the current flowing in its primary. Current transformers are commonly used in metering and protective relaying in the electrical power industry where they facilitate the safe measurement of large currents, often in the presence of high voltages. The current transformer safely isolates measurement and control circuitry from the high voltages typically present on the circuit being measured.

Current transformers are often constructed by passing a single primary turn (either an insulated cable or an uninsulated bus bar) through a well-insulated toroidal core wrapped with many turns of wire. The CT is typically described by its current ratio from primary to secondary. For example, a 4000:5 CT would provide an output current of 5 amperes when the primary was passing 4000 amperes. The secondary winding can be single ratio or have several tap points to provide a range of ratios. Care must be taken that the secondary winding is not disconnected from its load while current flows in the primary, as this will produce a dangerously high voltage across the open secondary and may permanently affect the accuracy of the transformer.

Specially constructed wideband CTs are also used, usually with an oscilloscope, to measure high frequency waveforms or pulsed currents within pulsed power systems. One type provides a voltage output that is proportional to the measured current; another, called a Rogowski coil, requires an external integrator in order to provide a proportional output.

Voltage transformers

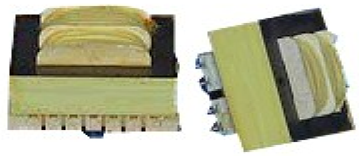
Voltage transformers (VTs) or potential transformers (PTs) are another type of instrument transformer, used for metering and protection in high-voltage circuits. They are designed to present negligible load to the supply being measured and to have a precise voltage ratio to accurately step down high voltages so that metering and protective relay equipment can be operated at a lower potential. Typically the secondary of a voltage transformer is rated for 69 or 120 Volts at rated primary voltage, to match the input ratings of protection relays.

The transformer winding high-voltage connection points are typically labelled as H1, H2 (sometimes H0 if it is internally grounded) and X1, X2, and sometimes an X3 tap may be present. Sometimes a second isolated winding (Y1, Y2, Y3) may also be available on the same voltage transformer. The high side (primary) may be connected phase to ground or phase to phase. The low side (secondary) is usually phase to ground.

The terminal identifications (H1, X1, Y1, etc.) are often referred to as polarity. This applies to current transformers as well. At any instant terminals with the same suffix numeral have the same polarity and phase. Correct identification of terminals and wiring is essential for proper operation of metering and protection relays.

While VTs were formerly used for all voltages greater than 240V primary, modern meters eliminate the need VTs for most secondary service voltages. VTs are typically used in circuits where the system voltage level is above 600 V. Modern meters eliminate the need of VT's since the voltage remains constant and it is measured in the incoming supply.

Pulse transformers



A **pulse transformer** is a transformer that is optimised for transmitting rectangular electrical pulses (that is, pulses with fast rise and fall times and a relatively constant amplitude). Small versions called *signal* types are used in digital logic and telecommunications circuits, often for matching logic drivers to transmission lines. Medium-sized *power* versions are used in power-control circuits such as camera flash controllers. Larger *power* versions are used in the electrical power distribution industry to interface low-voltage control circuitry to the high-voltage gates of power semiconductors. Special high voltage pulse transformers are also used to generate high power pulses for radar, particle accelerators, or other high energy pulsed power applications.

To minimise distortion of the pulse shape, a pulse transformer needs to have low values of leakage inductance and distributed capacitance, and a high open-circuit inductance. In power-type pulse transformers, a low coupling capacitance (between the primary and secondary) is important to protect the circuitry on the primary side from high-powered transients created by the load. For the same reason, high insulation resistance and high breakdown voltage are required. A good transient response is necessary to maintain the rectangular pulse shape at the secondary, because a pulse with slow edges would create switching losses in the power semiconductors.

The product of the peak pulse voltage and the duration of the pulse (or more accurately, the voltage-time integral) is often used to characterise pulse transformers. Generally speaking, the larger this product, the larger and more expensive the transformer.

Pulse transformers by definition have a duty cycle of less than 1, whatever energy stored in the coil during the pulse must be "dumped" out before the pulse is fired again.

Air-core transformers

These are used for high frequency work. The lack of a core means very low inductance. Such transformers may be nothing more than a few turns of wire soldered onto a printed circuit board.

Ferrite-core transformers

Widely used in intermediate frequency (IF) stages in super heterodyne radio receivers. These are mostly tuned transformers, containing a threaded ferrite slug that is screwed in or out to adjust IF tuning. The transformers are usually canned for stability and to reduce interference

Audio transformers

Transformers in a tube amplifier. Output transformers are on the left. The power supply toroidal transformer is on right.

Audio transformers are usually the factor which limits sound quality when used; electronic circuits with wide frequency response and low distortion are relatively simple to design.

Transformers are also used in DI boxes to convert high-impedance instrument signals (e.g. bass guitar) to low impedance signals to enable them to be connected to a microphone input on the mixing console.

A particularly critical component is the output transformer of an audio power amplifier. Valve circuits for quality reproduction have long been produced with no other (inter-stage) audio transformers, but an output transformer is needed to couple the relatively high impedance (up to a few hundred ohms depending upon configuration) of the output valve(s) to the low impedance of a loudspeaker. (The valves can deliver a low current at a high voltage; the speakers require high current at low voltage.) Most solid-state power amplifiers need no output transformer at all.

For good low-frequency response a relatively large iron core is required; high power handling increases the required core size. Good high-frequency response requires carefully designed and implemented windings without excessive leakage inductance or stray capacitance. All this makes for an expensive component.

Early transistor audio power amplifiers often had output transformers, but they were eliminated as designers discovered how to design amplifiers without them.

Capacitors

Function

Capacitors store electric charge. They are used with resistors in timing circuits because it takes time for a capacitor to fill with charge. They are used to smooth varying DC supplies by acting as a reservoir of charge. They are also used in filter circuits because capacitors easily pass AC (changing) signals but they block DC (constant) signals.

Capacitance

This is a measure of a capacitor's ability to store charge. A large capacitance means that more charge can be stored. Capacitance is measured in farads, symbol F. However 1F is very large, so prefixes are used to show the smaller values.

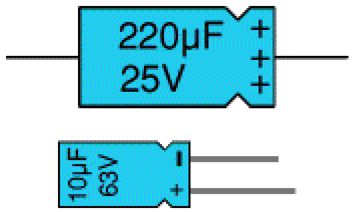
Three prefixes (multipliers) are used, µ (micro), n (nano) and p (pico):

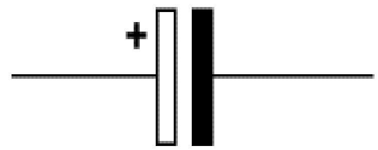
- µ means 10^{-6} (millionth), so 1000000µF = 1F
- n means 10^{-9} (thousand-millionth), so 1000nF = 1µF
- p means 10^{-12} (million-millionth), so 1000pF = 1nF

Capacitor values can be very difficult to find because there are many types of capacitor with different labeling systems!

There are many types of capacitor but they can be split into two groups, **polarised** and **unpolarised**. Each group has its own circuit symbol.

Polarised capacitors (large values, 1µF +)

Examples: 

Circuit symbol: 

Electrolytic Capacitors

Electrolytic capacitors are polarised and **they must be connected the correct way round**, at least one of their leads will be marked + or -. They are not damaged by heat when soldering.

There are two designs of electrolytic capacitors; **axial** where the leads are attached to each end (220µF in picture) and **radial** where both leads are at the same end (10µF in picture). Radial capacitors tend to be a little smaller and they stand upright on the circuit board.

It is easy to find the value of electrolytic capacitors because they are clearly printed with their capacitance and voltage rating. The voltage rating can be quite low (6V for example) and it should always be checked when selecting an electrolytic capacitor. If the project parts list does not specify a voltage, choose a capacitor with a rating which is greater than the project's power supply voltage. 25V is a sensible minimum most battery circuits.

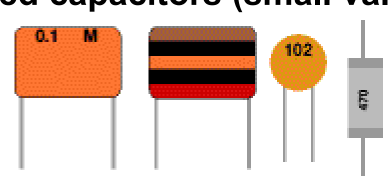
Tantalum Bead Capacitors

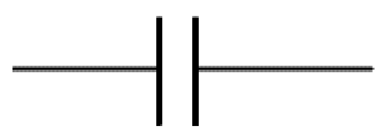
Tantalum bead capacitors are polarised and have low voltage ratings like electrolytic capacitors. They are expensive but very small, so they are used where a large capacitance is needed in a small size.

Modern tantalum bead capacitors are printed with their capacitance, voltage and polarity in full. However older ones use a colour-code system which has two stripes (for the two digits) and a spot of colour for the number of zeros to give the value in µF. The standard colour code is used, but for the spot, **grey** is used to mean × 0.01 and **white** means × 0.1 so that values of less than 10µF can be shown. A third colour stripe near the leads shows the voltage (yellow 6.3V, black 10V, green 16V, blue 20V, grey 25V, white 30V, pink 35V). The positive (+) lead is to the right when the spot is facing you: '**when the spot is in sight, the positive is to the right**'.

For	example:	**blue,**	**grey,**	**black**	**spot**	means	68µF
For	example:	**blue,**	**grey,**	**white**	**spot**	means	6.8µF
For	example:	**blue,**	**grey,**	**grey**	**spot**	means	0.68µF

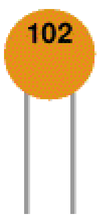
Unpolarised capacitors (small values, up to 1µF)

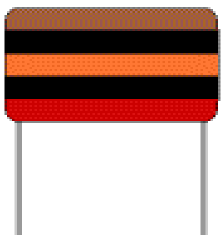
Examples: 

Circuit symbol: 

Small value capacitors are unpolarised and may be connected either way round. They are not damaged by heat when soldering, except for one unusual type (polystyrene). They have high voltage ratings of at least 50V, usually 250V or so. It can be difficult to find the values of these small capacitors because there are many types of them and several different labelling systems!

Many small value capacitors have their value printed but without a multiplier, so you need to use experience to work out what the multiplier should be!

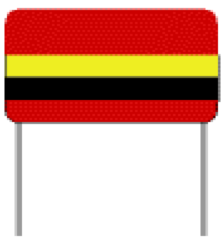




For example **0.1** means 0.1μF = 100nF.

Sometimes the multiplier is used in place of the decimal point: For example: **4n7** means 4.7nF.

Capacitor Number Code



A number code is often used on small capacitors where printing is difficult:

- the 1st number is the 1st digit,
- the 2nd number is the 2nd digit,
- the 3rd number is the number of zeros to give the capacitance in pF.
- Ignore any letters - they just indicate tolerance and voltage rating.

For example: **102** means 1000pF = 1nF *(not 102pF!)*

For example: **472J** means 4700pF = 4.7nF (J means 5% tolerance).

Capacitor Colour Code

Colour Code	
Colour	Number
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

A colour code was used on polyester capacitors for many years. It is now obsolete, but of course there are many still around. The colours should be read like the resistor code, the top three colour bands giving the value in pF. Ignore the 4th band (tolerance) and 5th band (voltage rating).

For example:

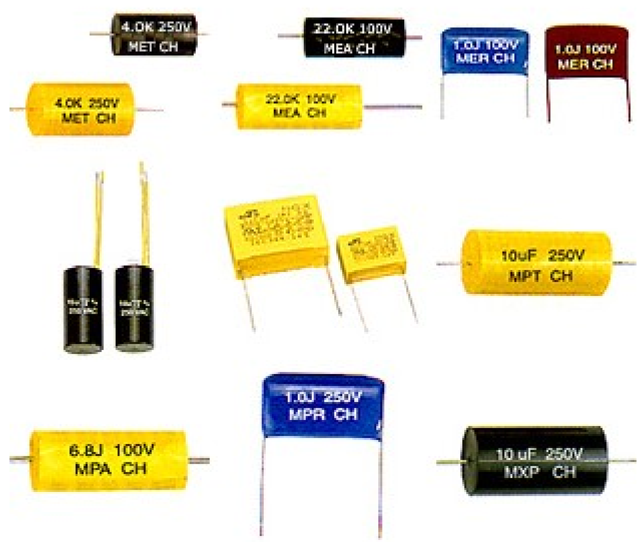
Brown, black, orange means 10000pF = 10nF = 0.01µF.

Note that there are no gaps between the colour bands, so 2 identical bands actually appear as a wide band.

For example:

Wide red, yellow means 220nF = 0.22µF.

Polystyrene Capacitors



This type is rarely used now. Their value (in pF) is normally printed without units. Polystyrene capacitors can be damaged by heat when soldering (it melts the polystyrene!) so you should use a heat sink (such as a crocodile clip). Clip the heat sink to the lead between the capacitor and the joint.

Real capacitor values (the E3 and E6 series)

You may have noticed that capacitors are not available with every possible value, for example 22µF and 47µF are readily available, but 25µF and 50µF are not!

Why is this? Imagine that you decided to make capacitors every 10µF giving 10, 20, 30, 40, 50 and so on. That seems fine, but what happens when you reach 1000? It would be pointless to make 1000, 1010, 1020, 1030 and so on because for these values 10 is a very small difference, too small to be noticeable in most circuits and capacitors cannot be made with that accuracy.

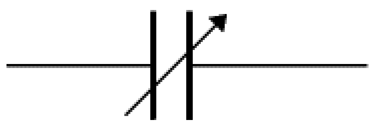
To produce a sensible range of capacitor values you need to increase the size of the 'step' as the value increases. The standard capacitor values are based on this idea and they form a series which follows the same pattern for every multiple of ten.

The E3 series (3 values for each multiple of ten)
10, 22, 47, ... then it continues 100, 220, 470, 1000, 2200, 4700, 10000 etc.
Notice how the step size increases as the value increases (values roughly double each time).

The E6 series (6 values for each multiple of ten)
10, 15, 22, 33, 47, 68, ... then it continues 100, 150, 220, 330, 470, 680, 1000 etc.
Notice how this is the E3 series with an extra value in the gaps.

The E3 series is the one most frequently used for capacitors because many types cannot be made with very accurate values.

Variable capacitors

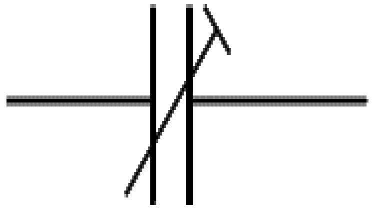

Variable Capacitor Symbol


Variable Capacitor

Variable capacitors are mostly used in radio tuning circuits and they are sometimes called 'tuning capacitors'. They have very small capacitance values, typically between 100pF and 500pF (100pF = 0.0001µF). The type illustrated usually has trimmers built in (for making small adjustments - see below) as well as the main variable capacitor.

Many variable capacitors have very short spindles which are not suitable for the standard knobs used for variable resistors and rotary switches. It would be wise to check that a suitable knob is available before ordering a variable capacitor.

Variable capacitors are **not** normally used in timing circuits because their capacitance is too small to be practical and the range of values available is very limited. Instead timing circuits use a fixed capacitor and a variable resistor if it is necessary to vary the time period.


Trimmer Capacitor Symbol

Trimmer capacitors

Trimmer capacitors (trimmers) are miniature variable capacitors. They are designed to be mounted directly onto the circuit board and adjusted only when the circuit is built.

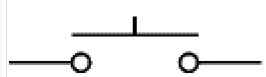

Trimmer Capacitor

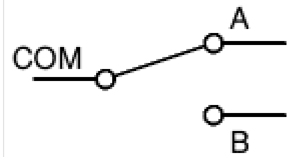
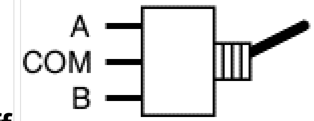
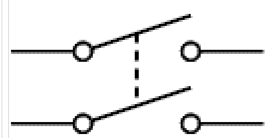
A small screwdriver or similar tool is required to adjust trimmers. The process of adjusting them requires patience because the presence of your hand and the tool will slightly change the capacitance of the circuit in the region of the trimmer!

Trimmer capacitors are only available with very small capacitances, normally less than 100pF. It is impossible to reduce their capacitance to zero, so they are usually specified by their minimum and maximum values, for example 2-10pF.

Trimmers are the capacitor equivalent of presets which are miniature variable resistors.

Standard Switches

Type of Switch	Circuit Symbol	Example
ON-OFF **Single Pole, Single Throw = SPST** A simple on-off switch. This type can be used to switch the power supply to a circuit. When used with mains electricity this type of switch *must* be in the live wire, but it is better to use a DPST switch to isolate both live and neutral.		 SPST toggle switch
(ON)-OFF **Push-to-make = SPST Momentary** A push-to-make switch returns to its normally open (off) position when you release the button, this is shown by the brackets around ON. This is the standard doorbell switch.		 Push-to-make switch
ON-(OFF) **Push-to-break = SPST Momentary** A push-to-break switch returns to its normally closed (on) position when you release the button.		 Push-to-break switch

ON-ON **Single Pole, Double Throw = SPDT** This switch can be on in both positions, switching on a separate device in each case. It is often called a **changeover switch.** For example, a SPDT switch can be used to switch on a red lamp in one position and a green lamp in the other position. A SPDT toggle switch may be used as a simple on-off switch by connecting to COM and one of the A or B terminals shown in the diagram. A and B are interchangeable so switches are usually not labelled. **ON-OFF-ON** **SPDT Centre Off** A special version of the standard SPDT switch. It has a third switching position in the centre which is off. Momentary (ON)-OFF-(ON) versions are also available where the switch returns to the central off position when released.	  	 SPDT toggle switch  SPDT slide switch (PCB mounting)  SPDT rocker switch
Dual ON-OFF **Double Pole, Single Throw = DPST** A pair of on-off switches which operate together (shown by the dotted line in the circuit symbol). A DPST switch is often used to switch mains electricity because it can isolate both the live and neutral connections.		 DPST rocker switch

Special Switches

Type of Switch	Example

Push-Push Switch (e.g. SPST = ON-OFF)

This looks like a momentary action push switch but it is a standard on-off switch: push once to switch on, push again to switch off. This is called a **latching action**.

Micro switch (usually SPDT = ON-ON)

Micro switches are designed to switch fully open or closed in response to small movements. They are available with levers and rollers attached.

Key switch

A key operated switch. The example shown is SPST.

Tilt Switch (SPST)

Tilt switches contain a conductive liquid and when tilted this bridges the contacts inside, closing the switch. They can be used as a sensor to detect the position of an object. Some tilt switches contain mercury which is poisonous.

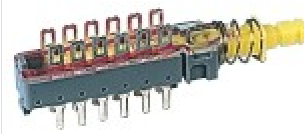
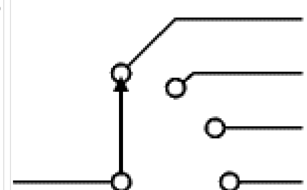
Reed Switch (usually SPST)

The contacts of a reed switch are closed by bringing a small magnet near the switch. They are used in security circuits, for example to check that doors are closed. Standard reed switches are SPST (simple on-off) but SPDT (changeover) versions are also available.

DIP Switch (DIP = Dual In-line Parallel)

This is a set of miniature SPST on-off switches, the example shown has 8 switches. The package is the same size as a standard DIL (Dual In-Line) integrated circuit.

This type of switch is used to set up circuits, e.g. setting the code

of a remote control.	
Multi-pole Switch The picture shows a 6-pole double throw switch, also known as a 6-pole changeover switch. It can be set to have momentary or latching action. Latching action means it behaves as a push-push switch, push once for the first position, push again for the second position etc.	
Multi-way Switch Multi-way switches have 3 or more conducting positions. They may have several poles (contact sets). A popular type has a rotary action and it is available with a range of contact arrangements from 1-pole 12-way to 4-pole 3 way. The number of ways (switch positions) may be reduced by adjusting a stop under the fixing nut. For example if you need a 2-pole 5-way switch you can buy the 2-pole 6-way version and adjust the stop. Contrast this multi-way switch (many switch positions) with the multi-pole switch (many contact sets) described above.	 Multi-way rotary switch  1-pole 4-way switch symbol

Relays

A relay is an electrically operated switch. Current flowing through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts. The coil current can be on or off so relays have two switch positions and they are double throw (changeover) switches.

Relays allow one circuit to switch a second circuit which can be completely separate from the first. For example a low voltage battery circuit can use a relay to switch a 230V AC mains circuit. There is no electrical connection inside the relay between the two circuits, the link is magnetic and mechanical.

The coil of a relay passes a relatively large current, typically 30mA for a 12V relay, but it can be as much as 100mA for relays designed to operate from lower voltages. Most ICs (chips) cannot provide this current and a transistor is usually used to amplify the small IC current to the larger value required for the relay coil. The maximum output current for the popular 555 timer IC is 200mA so these devices can supply relay coils directly without amplification.

Relays are usuallly SPDT or DPDT but they can have many more sets of switch contacts, for example relays with 4 sets of changeover contacts are readily available. For further information about switch contacts and the terms used to describe them please see the page on switches.

Most relays are designed for PCB mounting but you can solder wires directly to the pins providing you take care to avoid melting the plastic case of the relay.

The supplier's catalogue should show you the relay's connections. The coil will be obvious and it may be connected either way round. Relay coils produce brief high voltage 'spikes' when they are switched off and this can destroy transistors and ICs in the circuit. To prevent damage you must connect a protection diode across the relay coil.

The animated picture shows a working relay with its coil and switch contacts. You can see a lever on the left being attracted by magnetism when the coil is switched on. This lever moves the switch contacts. There is one set of contacts (SPDT) in the foreground and another behind them, making the relay DPDT.

The relay's switch connections are usually labelled COM, NC and NO:

COM = Common, always connect to this, it is the moving part of the switch.

NC = Normally Closed, COM is connected to this when the relay coil is off.

NO = Normally Open, COM is connected to this when the relay coil is on.

Connect to COM and NO if you want the switched circuit to be on when the relay coil is on.

Connect to COM and NC if you want the switched circuit to be on when the relay coil is off.

Choosing a relay

You need to consider several features when choosing a relay:

Physical size and pin arrangement

If you are choosing a relay for an existing PCB you will need to ensure that its dimensions and pin arrangement are suitable. You should find this information in the supplier's catalogue.

Coil voltage

The relay's coil voltage rating and resistance must suit the circuit powering the relay coil. Many relays have a coil rated for a 12V supply but 5V and 24V relays are also readily available. Some relays operate perfectly well with a supply voltage which is a little lower than their rated value.

Coil resistance

The circuit must be able to supply the current required by the relay coil. You can use Ohm's law to calculate the current: Relay coil current = supply voltage

Coil resistance

For example: A 12V supply relay with a coil resistance of 400 passes a current of 30mA. This is OK for a 555 timer IC (maximum output current 200mA), but it is too much for most ICs and they will require a transistor to amplify the current.

Switch ratings (voltage and current)

The relay's switch contacts must be suitable for the circuit they are to control. You will need to check the voltage and current ratings. Note that the voltage rating is usually higher for AC, for example: "5A at 24V DC or 125V AC".

Switch contact arrangement (SPDT, DPDT etc)

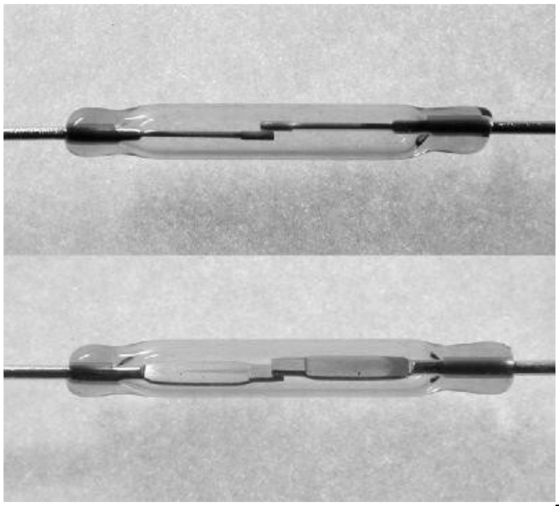
Most relays are SPDT or DPDT which are often described as "single pole changeover" (SPCO) or "double pole changeover" (DPCO). For further information please see the page on switches.

Protection diodes for relays

Transistors and ICs must be protected from the brief high voltage produced when a relay coil is switched off. The diagram shows how a signal diode (eg 1N4148) is connected 'backwards' across the relay coil to provide this protection.

Current flowing through a relay coil creates a magnetic field which collapses suddenly when the current is switched off. The sudden collapse of the magnetic field induces a brief high voltage across the relay coil which is very likely to damage transistors and ICs. The protection diode allows the induced voltage to drive a brief current through the coil (and diode) so the magnetic field dies away quickly rather than instantly. This prevents the induced voltage becoming high enough to cause damage to transistors and ICs.

Reed relays

Reed relays consist of a coil surrounding a reed switch. Reed switches are normally operated with a magnet, but in a reed relay current flows through the coil to create a magnetic field and close the reed switch.

Reed relays generally have higher coil resistances than standard relays (1000 for example) and a wide range of supply voltages (9-20V for example). They are capable of switching much more rapidly than standard relays, up to several hundred times per second; but they can only switch low currents (500mA maximum for example).

The reed relay shown in the photograph will plug into a standard 14-pin DIL socket ('IC holder').

For further information about reed switches please see the page on switche

Diode

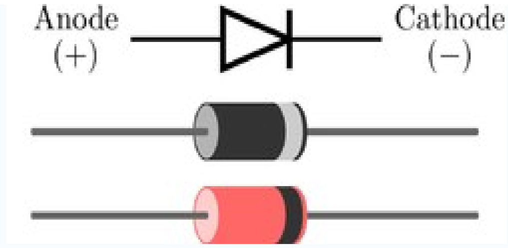
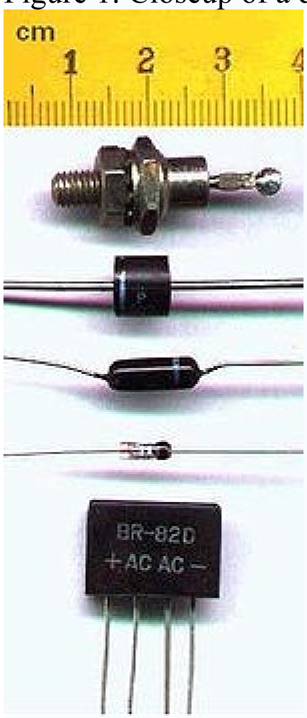


Figure 1: Closeup of a diode, showing the square shaped semiconductor crystal



In electronics, a **diode** is a two-terminal device (thermionic diodes may also have one or two ancillary terminals for a heater).

Diodes have two active electrodes between which the signal of interest may flow, and most are used for their unidirectional electric current property. The varicap diode is used as an electrically adjustable capacitor.

The directionality of current flow most diodes exhibit is sometimes generically called the *rectifying* property. The most common function of a diode is to allow an electric current to pass in one direction (called the *forward biased* condition) and to block the current in the opposite direction (the reverse biased condition). Thus, the diode can be thought of as an electronic version of a check valve.

Real diodes do not display such a perfect on-off directionality but have a more complex non-linear electrical characteristic, which depends on the particular type of diode technology. Diodes also have many other functions in which they are not designed to operate in this on-off manner.

Early diodes included “cat’s whisker” crystals and vacuum tube devices (also called **thermionic valves**). Today the most common diodes are made from semiconductor materials such as silicon or germanium

Semiconductor diodes

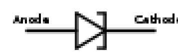
Most modern diodes are based on semiconductor p-n junctions. In a p-n diode, conventional current can flow from the p-type side (the anode) to the n-type side (the cathode), but cannot flow in the opposite direction. Another type of semiconductor diode, the Schottky diode, is formed from the contact between a metal and a semiconductor rather than by a p-n junction

Types of semiconductor diode

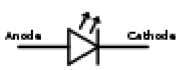
Diode

Zener diode

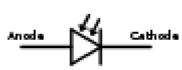
Schottky diode



Tunnel diode

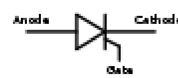


Light-emitting diode



Photodiode

Varector



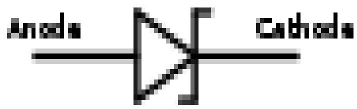
Silicon controlled rectifier

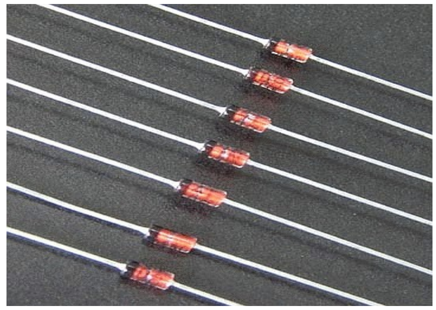
Figure: Typical diode packages in same alignment as diode symbol. Thin bar depicts the cathode.

There are several types of junction diodes, which either emphasize a different physical aspect of a diode often by geometric scaling, doping level, choosing the right electrodes, are just an application of a diode in a special circuit, or are really different devices like the Gunn and laser diode and the MOSFET:

Normal (p-n) diodes, which operate as described above, are usually made of doped silicon or, more rarely, germanium. Before the development of modern silicon power rectifier diodes, cuprous oxide and later selenium was used; its low efficiency gave it a much higher forward voltage drop (typically 1.4–1.7 V per “cell”, with multiple cells stacked to increase the peak inverse voltage rating in high voltage rectifiers), and required a large heat sink (often an extension of the diode’s metal substrate), much larger than a silicon diode of the same current ratings would require. The vast majority of all diodes are the p-n diodes found in CMOS integrated circuits, which include two diodes per pin and many other internal diodes.

Zener diode





Zener diode schematic symbol

Current-voltage characteristic of a Zener diode with a breakdown voltage of 17 volt. Notice the change of voltage scale between the forward biased (positive) direction and the reverse biased (negative) direction.

A **Zener diode** is a type of diode that permits current in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage". The device was named after Clarence Zener, who discovered this electrical property.

A conventional solid-state diode will not allow significant current if it is reverse-biased below its reverse breakdown voltage. When the reverse bias breakdown voltage is exceeded, a conventional diode is subject to high current due to avalanche breakdown. Unless this current is limited by external circuitry, the diode will be permanently damaged. In case of large forward bias (current in the direction of the arrow), the diode exhibits a voltage drop due to its junction built-in voltage and internal resistance. The amount of the voltage drop depends on the semiconductor material and the doping concentrations.

A **Zener diode** exhibits almost the same properties, except the device is specially designed so as to have a greatly reduced breakdown voltage, the so-called **Zener voltage**. A Zener diode contains a heavily doped p-n junction allowing electrons to tunnel from the valence band of the p-type material to the conduction band of the n-type material. In the atomic scale, this tunneling corresponds to the transport of valence band electrons into the empty conduction band states; as a result of the reduced barrier between these bands and high electric fields that are induced due to the relatively high levels of dopings on both sides. A reverse-biased Zener diode will exhibit a controlled breakdown and allow the current to keep the voltage across the Zener diode at the Zener voltage. For example, a diode with a Zener breakdown voltage of 3.2 V will exhibit a voltage drop of 3.2 V if reverse bias voltage applied across it is more than its Zener voltage. However, the current is not unlimited, so the Zener diode is typically used to generate a reference voltage for an amplifier stage, or as a voltage stabilizer for low-current applications.

The breakdown voltage can be controlled quite accurately in the doping process. While tolerances within 0.05% are available, the most widely used tolerances are 5% and 10%.

Another mechanism that produces a similar effect is the avalanche effect as in the avalanche diode. The two types of diode are in fact constructed the same way and both effects are present in diodes of this type. In silicon diodes up to about 5.6 volts, the Zener effect is the predominant effect and shows a marked negative temperature coefficient. Above 5.6 volts, the avalanche effect becomes predominant and exhibits a positive temperature coefficient.

In a 5.6 V diode, the two effects occur together and their temperature coefficients neatly cancel each other out, thus the 5.6 V diode is the component of choice in temperature-critical applications.

Modern manufacturing techniques have produced devices with voltages lower than 5.6 V with negligible temperature coefficients, but as higher voltage devices are encountered, the temperature coefficient rises dramatically. A 75 V diode has 10 times the coefficient of a 12 V diode.

All such diodes, regardless of breakdown voltage, are usually marketed under the umbrella term of "Zener diode".

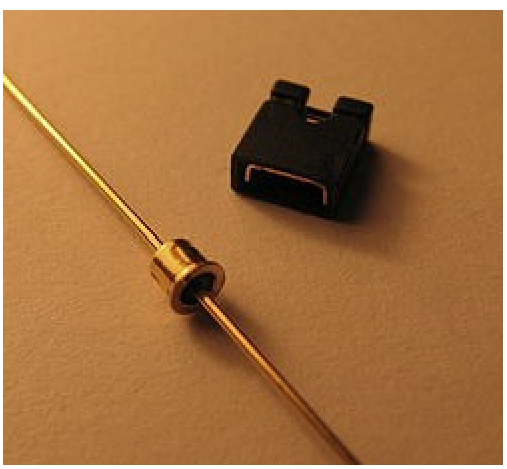
Uses

Zener diode shown with typical packages. *Reverse* current $-i_Z$ is shown.

Zener diodes are widely used to regulate the voltage across a circuit. When connected in parallel with a variable voltage source so that it is reverse biased, a Zener diode conducts when the voltage reaches the diode's reverse breakdown voltage. From that point it keeps the voltage at that value.

Tunnel diode

Tunnel diode schematic symbol



1N3716 tunnel diode (with jumper for scale)

A **tunnel diode** or **Esaki diode** is a type of semiconductor diode which is capable of very fast operation, well into the microwave frequency region, by using quantum mechanical effects.

It was invented in August 1957 by Leo Esaki when he was with Tokyo Tsushin Kogyo (now known as Sony), who in 1973 received the Nobel Prize in Physics for discovering the electron tunneling effect used in these diodes.

These diodes have a heavily doped p-n junction only some 10 nm (100 Å) wide. The heavy doping results in a broken bandgap, where conduction band electron states on the n-side are more or less aligned with valence band hole states on the p-side.

Tunnel diodes were manufactured by SONY for the first time in 1957 [1] followed by General Electric and other companies from about 1960, and are still made in low volume today. [2] Tunnel diodes are usually made from germanium, but can also be made in gallium arsenide and silicon materials. They can be used as oscillators, amplifiers, frequency converters and detectors. [3]

Light-emitting diode

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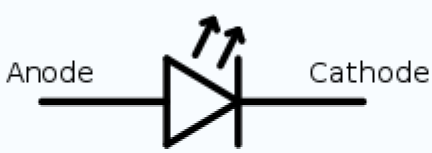
Blue, green, and red LEDs; these can be combined to produce most perceptible colors, including white. Infrared and ultraviolet (UVA) LEDs are also available.



LED schematic symbol

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A **light-emitting-diode** (**LED**) is a semiconductor diode that emits light when an electric current is applied in the forward direction of the device, as in the simple LED circuit. The effect is a form of electroluminescence where incoherent and narrow-spectrum light is emitted from the p-n junction in a solid state material.

LEDs are widely used as indicator lights on electronic devices and increasingly in higher power applications such as flashlights and area lighting. An LED is usually a small area (less than 1 mm^2) light source, often with optics added directly on top of the chip to shape its radiation pattern and assist in reflection.[2][3] The color of the emitted light depends on the composition and condition of the semi conducting material used, and can be infrared, visible, or ultraviolet. Besides lighting, interesting

applications include using UV-LEDs for sterilization of water and disinfection of devices,[4] and as a grow light to enhance photosynthesis in plants.[5]

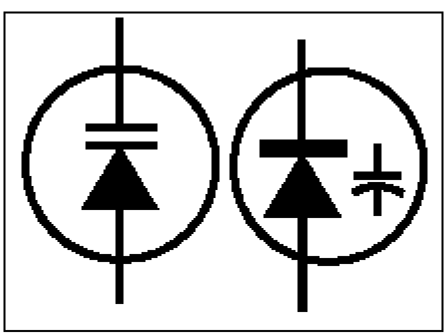
Photodiode

A photodiode

A **photodiode** is a type of photodetector capable of converting light into either current or voltage, depending upon the mode of operation.[1]

Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fibre connection to allow light to reach the sensitive part of the device. Many diodes designed for use specifically as a photodiode will also use a PIN junction rather than the typical PN junction.

Varactor Diode



From Wikipedia, the free encyclopedia

(Redirected from Varactor diode)

Jump to: navigation, search

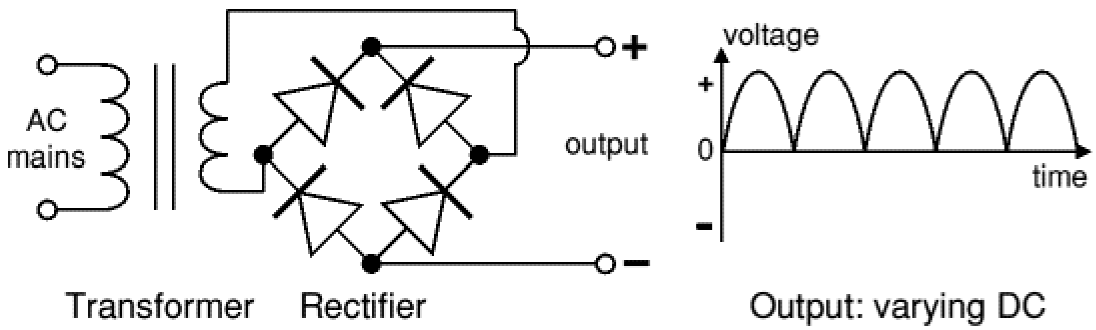
Varicap schematic symbol

In electronics, a **varicap diode**, **varactor diode**, **variable capacitance diode** or **tuning diode** is a type of diode which has a variable capacitance that is a function of the voltage impressed on its terminals.

Applications

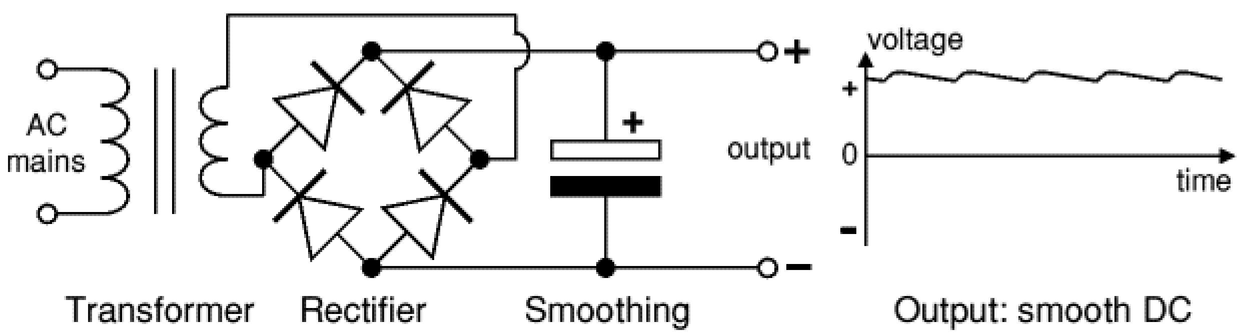
Varactors are principally used as a voltage-controlled capacitor, rather than as rectifiers. They are commonly used in parametric amplifiers, parametric oscillators and voltage-controlled oscillators as part of phase-locked loops and frequency synthesizers.

Transformer + Rectifier



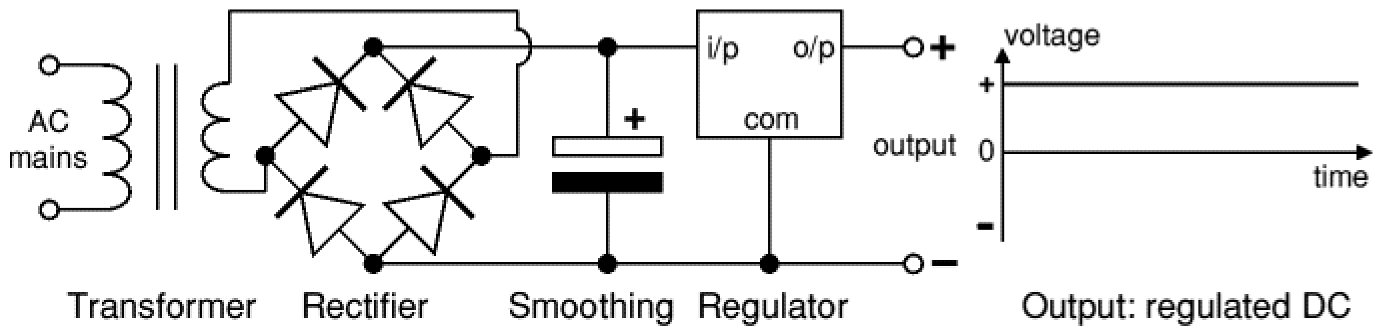
The **varying DC** output is suitable for lamps, heaters and standard motors. It is **not** suitable for electronic circuits unless they include a smoothing capacitor.

Transformer + Rectifier + Smoothing



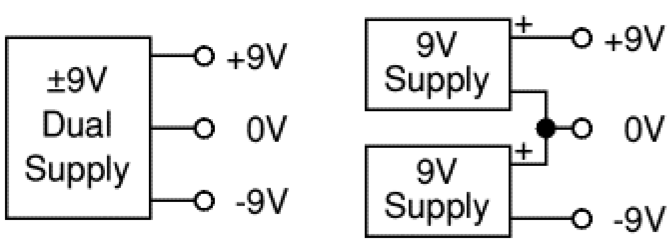
The **smooth DC** output has a small ripple. It is suitable for most electronic circuits.

Transformer + Rectifier + Smoothing + Regulator



The **regulated DC** output is very smooth with no ripple. It is suitable for all electronic circuits.

Dual Supplies



Some electronic circuits require a power supply with positive and negative outputs as well as zero volts (0V). This is called a 'dual supply' because it is like two ordinary supplies connected together as shown in the diagram.

Dual supplies have three outputs, for example a ±9V supply has +9V, 0V and -9V outputs.

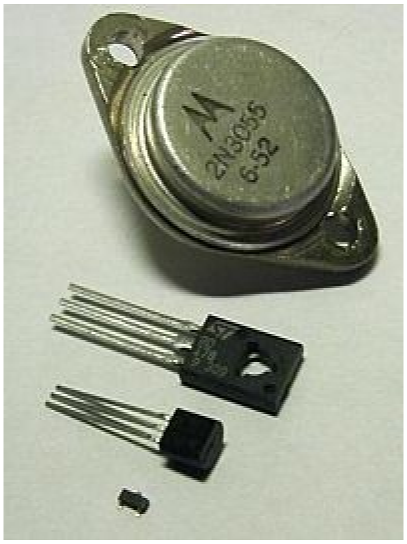
Transistors

Function

Transistors **amplify current**, for example they can be used to amplify the small output current from a logic IC so that it can operate a lamp, relay or other high current device. In many circuits a resistor is used to convert the changing current to a changing voltage, so the transistor is being used to **amplify voltage**.

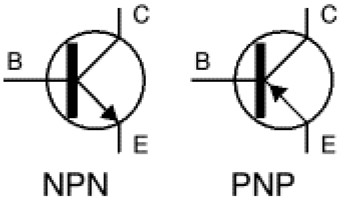
A transistor may be used as a **switch** (either fully on with maximum current, or fully off with no current) and as an **amplifier** (always partly on).

The amount of current amplification is called the **current gain**, symbol h_{FE}.
For further information please see the Transistor Circuits page.



Types of transistor

There are two types of standard transistors, **NPN** and **PNP**, with different circuit symbols. The letters refer to the layers of semiconductor material used to make the transistor. Most transistors used today are NPN because this is the easiest type to make from silicon. If you are new to electronics it is best to start by learning how to use NPN transistors.



Transistor circuit symbols

The leads are labelled **base** (B), **collector** (C) and **emitter** (E).
These terms refer to the internal operation of a transistor but they are not much help in understanding how a transistor is used, so just treat them as labels!

NPN

The symbol of an NPN Bipolar Junction Transistor.

NPN is one of the two types of bipolar transistors, in which the letters "N" and "P" refer to the majority charge carriers inside the different regions of the transistor. Most bipolar transistors used today are NPN, because electron mobility is higher than hole mobility in semiconductors, allowing greater currents and faster operation.

NPN transistors consist of a layer of P-doped semiconductor (the "base") between two N-doped layers. A small current entering the base in common-emitter mode is amplified in the collector output. In other terms, an NPN transistor is "on" when its base is pulled **high** relative to the emitter.

The arrow in the NPN transistor symbol is on the emitter leg and points in the direction of the conventional current flow when the device is in forward active mode.

One mnemonic device for identifying the symbol for the NPN transistor is "**n**ot **p**ointing i**n**"[5] or "**n**ever **p**oints i**n**".

PNP

The other type of BJT is the PNP with the letters "P" and "N" referring to the majority charge carriers inside the different regions of the transistor.

The symbol of a PNP Bipolar Junction Transistor.

PNP transistors consist of a layer of N-doped semiconductor between two layers of P-doped material. A small current leaving the base in common-emitter mode is amplified in the collector output. In other terms, a PNP transistor is "on" when its base is pulled **low** relative to the emitter.

The arrow in the PNP transistor symbol is on the emitter leg and points in the direction of the conventional current flow when the device is in forward active mode.

One mnemonic device for identifying the symbol for the PNP transistor is "**p**oints i**n** **p**roudly"[5] or "**p**oints i**n** **p**ermanently".

A Darlington pair is two transistors connected together to give a very high current gain.

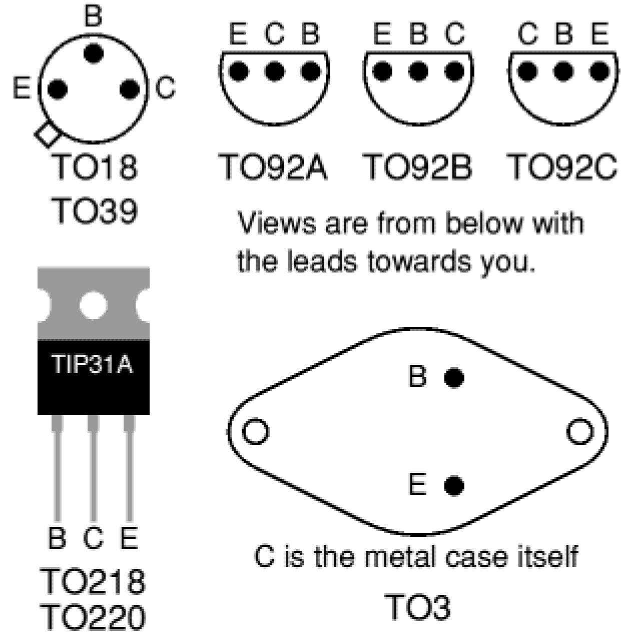
In addition to standard (bipolar junction) transistors, there are **field-effect transistors** which are usually referred to as **FET**s. They have different circuit symbols and properties and they are not (yet) covered by this page.

Connecting

Transistors have three leads which must be connected the correct way round. Please take care with this because a wrongly connected transistor may be damaged instantly when you switch on.

If you are lucky the orientation of the transistor will be clear from the PCB or stripboard layout diagram, otherwise you will need to refer to a supplier's catalogue to identify the leads.

The drawings on the right show the leads for some of the most common case styles.



Transistor leads for some common case styles.

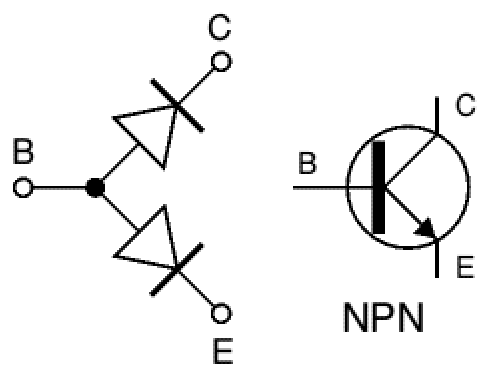
Please note that transistor lead diagrams show the view from **below** with the leads towards you. This is the opposite of IC (chip) pin diagrams which show the view from above.

Testing a transistor

Transistors can be damaged by heat when soldering or by misuse in a circuit. If you suspect that a transistor may be damaged there are two easy ways to test it:

1. Testing with a multimeter

Use a multimeter or a simple tester (battery, resistor and LED) to check each pair of leads for conduction. Set a digital multimeter to diode test and an analogue multimeter to a low resistance range.



Testing an NPN transistor

Test each pair of leads both ways (six tests in total):

- The **base-emitter (BE)** junction should behave like a diode and conduct one way only.
- The **base-collector (BC)** junction should behave like a diode and conduct one way only.
- The **collector-emitter (CE)** should not conduct either way.

The diagram shows how the junctions behave in an NPN transistor. The diodes are reversed in a PNP transistor but the same test procedure can be used.

Testing in a simple switching circuit

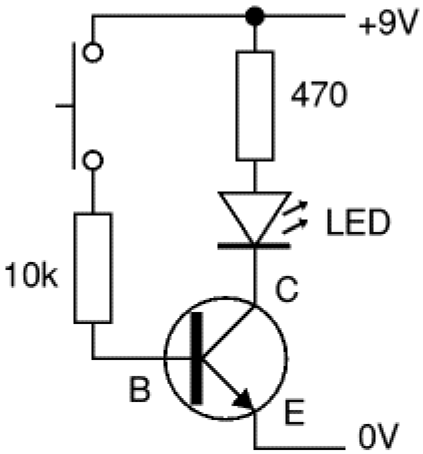
Connect the transistor into the circuit shown on the right which uses the transistor as a switch. The supply voltage is not critical, anything between 5 and 12V is suitable. This circuit can be

quickly built on breadboard for example. Take care to include the 10kΩ resistor in the base connection or you will destroy the transistor as you test it!

If the transistor is OK the LED should light when the switch is pressed and not light when the switch is released.

To test a PNP transistor use the same circuit but reverse the LED and the supply voltage.

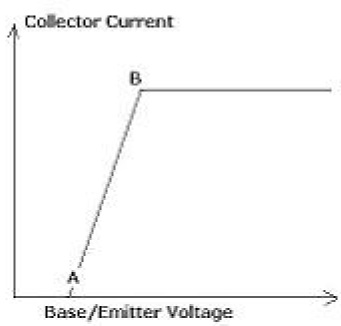
Some multimeters have a 'transistor test' function which provides a known base current and measures the collector current so as to display the transistor's DC current gain h_{FE}.



How a transistor works

Amplifier circuit, standard common-emitter configuration.

Simple circuit using a transistor.



Operation graph of a transistor.

The essential usefulness of a transistor comes from its ability to use a small signal applied between one pair of its terminals to control a much larger signal at another pair of terminals. This property is called "gain". A transistor can control its output in proportion to the input signal; this is called an "amplifier".

Or, the transistor can be used to turn current on or off in a circuit like an electrically controlled "switch", where the amount of current is determined by other circuit elements.

The two types of transistors have slight differences in how they are used in a circuit. A bipolar transistor has terminals labelled base, collector and emitter. A small current at base terminal can control or switch a much larger current between collector and emitter terminals. For a field-effect transistor, the terminals are labelled gate, source, and drain, and a voltage at the gate can control a current between source and drain.

The image to the right represents a typical bipolar transistor in a circuit. Charge will flow between emitter and collector terminals depending on the current in the base. Since internally the base and emitter connections behave like a semiconductor diode, a voltage drop develops between base and emitter while the base current exists. The size of this voltage depends on the material the transistor is made from, and is referred to as V_{be}.

Transistor as a switch

Transistors are commonly used as electronic switches, for both high power applications including switched-mode power supplies and low power applications such as logic gates.

It can be seen from the graph that once the base voltage reaches a certain level, shown at B, no more current will exist and the output will be held at a fixed voltage. The transistor is then said to be saturated. Hence, values of input voltage can be chosen such that the output is either completely off,[7] or completely on. The transistor is acting as a switch, and this type of operation is common in digital circuits where only "on" and "off" values are relevant.

Transistor as an amplifier

The above common emitter amplifier is designed so that a small change in voltage in (V_{in}) changes the small current through the base of the transistor and the transistor's current amplification combined with the properties of the circuit mean that small swings in V_{in} produce large changes in V_{out}.

It is important that the operating parameters of the transistor are chosen and the circuit designed such that as far as possible the transistor operates within a linear portion of the graph, such as that shown between A and B, otherwise the output signal will suffer distortion.

Various configurations of single transistor amplifier are possible, with some providing current gain, some voltage gain, and some both.

From mobile phones to televisions, vast numbers of products include amplifiers for sound reproduction, radio transmission, and signal processing. The first discrete transistor audio amplifiers barely supplied a few hundred milliwatts, but power and audio fidelity gradually increased as better transistors became available and amplifier architecture evolved.

Modern transistor audio amplifiers of up to a few hundred watts are common and relatively inexpensive.

Some musical instrument amplifier manufacturers mix transistors and vacuum tubes in the same circuit, as some believe tubes have a distinctive sound.

Field-effect transistor

High-power N-channel field-effect transistor

The **field-effect transistor** (FET) is a type of transistor that relies on an electric field to control the shape and hence the conductivity of a channel of one type of charge carrier in a semiconductor material. FETs are sometimes called *unipolar transistors* to contrast their single-carrier-type operation with the dual-carrier-type operation of bipolar (junction) transistors (BJT). The *concept* of the FET predates the BJT, though it was not physically implemented until *after* BJTs due to the limitations of semiconductor materials and relative ease of manufacturing BJTs compared to FETs at the time.

Terminals

All FETs have a *gate*, *drain*, and *source* terminal that are roughly similar to the *base*, *collector*, and *emitter* of BJTs. Aside from the JFET, all FETs also have a fourth terminal called the *body*, *base*, *bulk*, or *substrate.* This fourth terminal serves the technical purpose of biasing the transistor into operation; it is rare to make non-trivial use of the body terminal in circuit designs, but its presence is important when setting up the physical layout of an integrated circuit.

Cross Section of an n-type MOSFET

The names of the terminals refer to their functions. The gate terminal may be thought of as controlling the opening and closing of a physical gate. This gate permits electrons to flow through or blocks their passage by creating or eliminating a channel between the source and drain. Electrons flow from the source terminal towards the drain terminal if influenced by an applied voltage. The body simply refers to the bulk of the semiconductor in which the gate, source and drain lie. Usually the body terminal is connected to the highest or lowest voltage within the circuit, depending on type. The body terminal and the source terminal are sometimes connected together since the source is also sometimes connected to the highest or lowest voltage within the circuit, however there are several uses of FETs which do not have such a configuration, such as transmission gates and cascode circuits

FET operation

The FET controls the flow of electrons (or electron holes) from the source to drain by affecting the size and shape of a "conductive channel" created and influenced by voltage (or lack of voltage) applied across the gate and source terminals. (For ease of discussion, this assumes body and source are connected). This conductive channel is the "stream" through which electrons flow from source to drain.

Consider an **n-channel "depletion-mode" device**. A negative gate-to-source voltage causes a *depletion region* to expand in width and encroach on the channel from the sides, narrowing the channel. If the depletion region expands to completely close the channel, the resistance of the channel from source to drain becomes large, and the FET is effectively turned off like a switch. Likewise a positive gate-to-source voltage increases the channel size and allows electrons to flow easily.

Now consider an **n-channel "enhancement-mode" device**. A positive gate-to-source voltage is necessary to create a conductive channel, since one does not exist naturally within the transistor. The positive voltage attracts free-floating electrons within the body towards the gate, forming a conductive channel. But first, enough electrons must be attracted near the gate to counter the dopant ions added to the body of the FET; this forms a region free of mobile carriers called a depletion region, and the phenomenon is referred to as the *threshold voltage* of the FET. Further gate-to-source voltage increase will attract even more electrons towards the gate which are able to create a conductive channel from source to drain; this process is called *inversion*.

For either enhancement- or depletion-mode devices, at drain-to-source voltages much less than gate-to-source voltages, changing the gate voltage will alter the channel resistance, and drain current will be proportional to drain voltage (referenced to source voltage). In this mode the FET operates like a variable resistor and the FET is said to be operating in a *linear mode* or *ohmic mode*.[1][2]

If drain-to-source voltage is increased, this creates a significant asymmetrical change in the shape of the channel due to a gradient of voltage potential from source to drain. The shape of the inversion region becomes "pinched-off" near the drain end of the channel. If drain-to-source voltage is increased further, the pinch-off point of the channel begins to move away from the drain towards the source. The FET is said to be in *saturation mode*;[3] some authors refer to it as *active mode*, for a better analogy with bipolar transistor operating regions.[4][5] The saturation mode, or the region between ohmic and saturation, is used when amplification is needed. The in-between region is sometimes considered to be part of the ohmic or linear region, even where drain current is not approximately linear with drain voltage.

Even though the conductive channel formed by gate-to-source voltage no longer connects source to drain during saturation mode, carriers are not blocked from flowing. Considering again an n-channel device, a depletion region exists in the p-type body, surrounding the conductive channel and drain and source regions. The electrons which comprise the channel are free to move out of the channel through the depletion region if attracted to the drain by drain-to-source voltage. The depletion region is free of carriers and has a resistance similar to silicon. Any increase of the drain-to-source voltage will increase the distance from drain to the pinch-off point, increasing resistance due to the depletion region proportionally to the applied drain-to-source voltage. This proportional change causes the drain-to-source current to remain relatively fixed independent of changes to the drain-to-source voltage and quite unlike the linear mode operation. Thus in saturation mode, the FET behaves as a constant-current source rather than as a resistor and can be used most effectively as a voltage amplifier. In this case, the gate-to-source voltage determines the level of constant current through the channel.

Uses

The most commonly used FET is the MOSFET. The CMOS (complementary-symmetry metal oxide semiconductor) process technology is the basis for modern digital integrated circuits. This process technology uses an arrangement where the (usually "enhancement-mode") p-channel MOSFET and n-channel MOSFET are connected in series such that when one is on, the other is off.

The fragile insulating layer of the MOSFET between the gate and channel makes it vulnerable to electrostatic damage during handling. This is not usually a problem after the device has been installed.

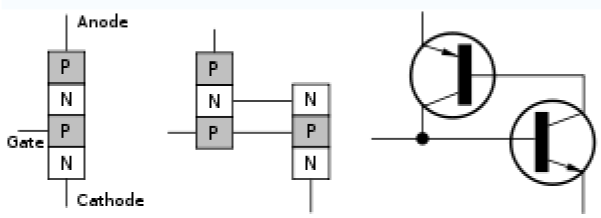
In FETs electrons can flow in either direction through the channel when operated in the linear mode, and the naming convention of drain terminal and source terminal is somewhat arbitrary, as the devices are typically (but not always) built symmetrically from source to drain. This makes FETs suitable for switching analog signals between paths (multiplexing). With this concept, one can construct a solid-state mixing board, for example.

Silicon-controlled rectifier (SCR)

A **silicon-controlled rectifier** (or **semiconductor-controlled rectifier**) is a four-layer solid state device that controls current. The name "silicon controlled rectifier" or **SCR** is General Electric's trade name for a type of thyristor. The SCR was developed by a team of power engineers led by Gordon Hall and commercialised by Frank W. "Bill" Gutzwiller in 1957.

Theory of operation

An SCR is a type of rectifier, controlled by a logic gate signal. It is a four-layer, three-terminal device. A p-type layer acts as an anode and an n-type layer as a cathode; the p-type layer closer to the n-type(cathode) acts as a gate.



An SCR (left) can be thought of as two BJT's working together (right).

Modes of operation

In the normal "off" state, the device restricts current to the leakage current. When the gate to cathode voltage exceeds a certain threshold, the device turns "on" and conducts current. The device will remain in the "on" state even after gate current is removed so long as current through the device remains above the holding current. Once current falls below the holding current for an appropriate period of time, the device will switch "off".

If the applied voltage increases rapidly enough, capacitive coupling may induce enough charge into the gate to trigger the device into the "on" state; this is referred to as "dv/dt triggering." This is usually

prevented by limiting the rate of voltage rise across the device, perhaps by using a snubber. "dv/dt triggering" may not switch the SCR into full conduction rapidly and the partially-triggered SCR may dissipate more power than is usual, possibly harming the device.

SCRs can also be triggered by increasing the forward voltage beyond their rated breakdown voltage (also called as breakover voltage), but again, this does not rapidly switch the entire device into conduction and so may be harmful so this mode of operation is also usually avoided. Also, the actual

breakdown voltage may be substantially higher than the rated breakdown voltage, so the exact trigger point will vary from device to device.

SCRs are made with voltage ratings of up to 7500 volts, and with current ratings up to 3000 RMS amperes per device. Some of the larger ones can take over 50 kA in single-pulse operation. SCRs are used in power switching, phase control, chopper, battery chargers, and inverter circuits. Industrially they are applied to produce variable DC voltages for motors (from a few to several thousand HP) from AC line voltage. They control the bulk of the dimmers used in stage lighting, and can also be used in some electric vehicles to modulate the working voltage in a Jacobson circuit. Another common application is phase control circuits used with inductive loads. SCRs can also be found in welding power supplies where they are used to maintain a constant output current or voltage. Large silicon-controlled rectifer assemblies with many individual devices connected in series are used in high-voltage DC converter stations.

Two SCRs in "inverse parallel" are often used in place of a TRIAC for switching inductive loads on AC circuits. Because each SCR only conducts for half of the power cycle and is reverse-biased for the other half-cycle, turn-off of the SCRs is assured. By comparison, the TRIAC is capable of conducting current in both directions and assuring that it switches "off" during the brief zero-crossing of current can be difficult.

Typical electrostatic discharge (ESD) protection structures in integrated circuits produce a parasitic SCR. This SCR is undesired; if it is triggered by accident, the IC can go into latchup and potentially be destroyed

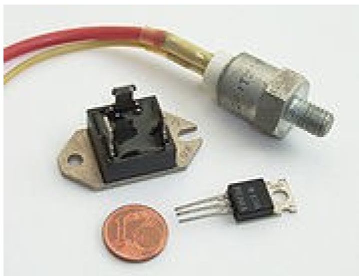
TRIAC

A **TRIAC**, or **TRIode for Alternating Current** is an electronic component approximately equivalent to two silicon-controlled rectifiers (SCRs/thyristors) joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together. Formal name for a TRIAC is **bidirectional triode thyristor**. This results in a bidirectional electronic switch which can conduct current in either direction when it is triggered (turned on). And thus doesn't have any polarity. It can be triggered by either a positive or a negative voltage being applied to its *gate* electrode (with respect to A1, otherwise known as MT1). Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, such as at the end of a half-cycle of alternating current (AC) mains power. This makes the TRIAC a very convenient switch for AC circuits, allowing the control of very large power flows with milliampere-scale control currents. In addition, applying a trigger pulse at a controllable point in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load (so-called *phase control*).

Low power TRIACs are used in many applications such as light dimmers, speed controls for electric fans and other electric motors, and in the modern computerized control circuits of many household small and major appliances. However, when used with inductive loads such as electric fans, care must be taken to assure that the TRIAC will turn off correctly at the end of each half-cycle of the ac power.

A snubber circuit is often used to assist this turn off. Snubber circuits are also used to prevent premature triggering. For higher-powered, more-demanding loads, two SCRs in inverse parallel may be used instead of one TRIAC. Because each SCR will have an entire half-cycle of reverse polarity voltage applied to it, turn-off of the SCRs is assured, no matter what the character of the load.

Triac Schematic Symbol



Triacs

DIAC

The **DIAC**, or **diode for alternating current**, is a bidirectional trigger diode that conducts current only after its breakdown voltage has been exceeded momentarily. When this occurs, the resistance of the diode abruptly decreases, leading to a sharp decrease in the voltage drop across the diode and, usually, a sharp increase in current flow through the diode. The diode remains "in conduction" until the current flow through it drops below a value characteristic for the device, called the holding current. Below this value, the diode switches back to its high-resistance (non-conducting) state. When used in AC applications this automatically happens when the current reverses polarity.

Typical Diac voltage and current relationships. Once the voltage exceeds the turn-on threshold, the device turns on and the voltage rapidly falls while the current increases.

The behavior is typically the same for both directions of current flow. Most DIACs have a breakdown voltage around 30 V. In this way, their behavior is somewhat similar to (but much more precisely controlled and taking place at lower voltages than) a neon lamp.

DIACs are a form of thyristor but without a gate electrode. They are typically used for triggering both thyristors and TRIACs - a bidirectional member of the thyristor family. Because of this common usage, many TRIACs contain a built-in DIAC in series with the TRIAC's "gate" terminal.

DIACs are also called *symmetrical trigger diodes* due to the symmetry of their characteristic curve. Because DIACs are bidirectional devices, their terminals are not labeled as *anode* or *cathode* but as A1 and A2 or MT1 ("Main Terminal") and MT2.

ICs

Analog

The MOSFET's advantages in most digital circuits do not translate into supremacy in all analog circuits. The two types of circuit draw upon different features of transistor behavior. Digital circuits switch, spending most of their time outside the switching region, while analog circuits depend on MOSFET behavior held precisely in the switching region of operation. The bipolar junction transistor (BJT) has traditionally been the analog designer's transistor of choice, due largely to its higher transconductance and its higher output impedance (drain-voltage independence) in the switching region.

Nevertheless, MOSFETs are widely used in many types of analog circuits because of certain advantages. The characteristics and performance of many analog circuits can be designed by changing the sizes (length and width) of the MOSFETs used. By comparison, in most bipolar transistors the size of the device does not significantly affect the performance. MOSFETs' ideal characteristics regarding gate current (zero) and drain-source offset voltage (zero) also make them nearly ideal switch elements, and also make switched capacitor analog circuits practical. In their linear region, MOSFETs can be used as precision resistors, which can have a much higher controlled resistance than BJTs. In high power circuits, MOSFETs sometimes have the advantage of not suffering from thermal runaway as BJTs do. Also, they can be formed into capacitors and gyrator circuits which allow op-amps made from them to appear as inductors, thereby allowing all of the normal analog devices, except for diodes (which can be made smaller than a MOSFET anyway), to be built entirely out of MOSFETs. This allows for complete analog circuits to be made on a silicon chip in a much smaller space.

Some ICs combine analog and digital MOSFET circuitry on a single mixed-signal integrated circuit, making the needed board space even smaller. This creates a need to isolate the analog circuits from the digital circuits on a chip level, leading to the use of isolation rings and Silicon-On-Insulator (SOI). The main advantage of BJTs versus MOSFETs in the analog design process is the ability of BJTs to handle a larger current in a smaller space. Fabrication processes exist that incorporate BJTs and MOSFETs into a single device. Mixed-transistor devices are called Bi-FETs (Bipolar-FETs) if they contain just one BJT-FET and BiCMOS (bipolar-CMOS) if they contain complementary BJT-FETs. Such devices have the advantages of both insulated gates and higher current density.

BJTs have some advantages over MOSFETs for at least two digital applications. Firstly, in high speed switching, they do not have the "larger" capacitance from the gate, which when multiplied by the resistance of the channel gives the intrinsic time constant of the process. The intrinsic time constant places a limit on the speed a MOSFET can operate at because higher frequency signals are filtered out. Widening the channel reduces the resistance of the channel, but increases the capacitance by the exact same amount. Reducing the width of the channel increases the resistance, but reduces the capacitance by the same amount. R*C=Tc1, 0.5R*2C=Tc1, 2R*0.5C=Tc1. There is no way to minimize the intrinsic time constant for a certain process. Different processes using different channel lengths, channel heights, gate thicknesses and materials will have different intrinsic time constants. This problem is mostly avoided with a BJT because it does not have a gate.

The second application where BJTs have an advantage over MOSFETs stems from the first. When driving many other gates, called fanout, the resistance of the MOSFET is in series with the gate capacitances of the other FETs, creating a secondary time constant. Delay circuits use this fact to create a fixed signal delay by using a small CMOS device to send a signal to many other, many times larger

CMOS devices. The secondary time constant can be minimized by increasing the driving FET's channel width to decrease its resistance and decreasing the channel widths of the FETs being driven, decreasing

their capacitance. The drawback is that it increases the capacitance of the driving FET and increases the resistance of the FETs being driven, but usually these drawbacks are a minimal problem when compared to the timing problem. BJTs are better able to drive the other gates because they can output more current than MOSFETs, allowing for the FETs being driven to charge faster. Many chips use MOSFET inputs and BiCMOS (see above) outputs.

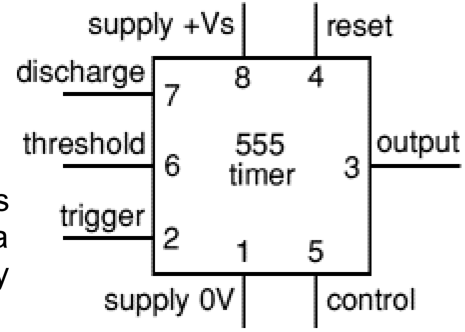
Digital

The growth of digital technologies like the microprocessor has provided the motivation to advance MOSFET technology faster than any other type of silicon-based transistor. A timeline can be found at computerhistory.org.[21] A big advantage of MOSFETs for digital switching is that the oxide layer between the gate and the channel prevents DC current from flowing through the gate, further reducing power consumption and giving a very large input impedance. The insulating oxide between the gate and channel effectively isolates a MOSFET in one logic stage from earlier and later stages, which allows a single MOSFET output to drive a considerable number of MOSFET inputs. Bipolar transistor-based logic (such as TTL) does not have such a high fanout capacity. This isolation also makes it easier for the designers to ignore to some extent loading effects between logic stages independently. That extent is defined by the operating frequency: as frequencies increase, the input impedance of the MOSFETs decreases.

CMOS

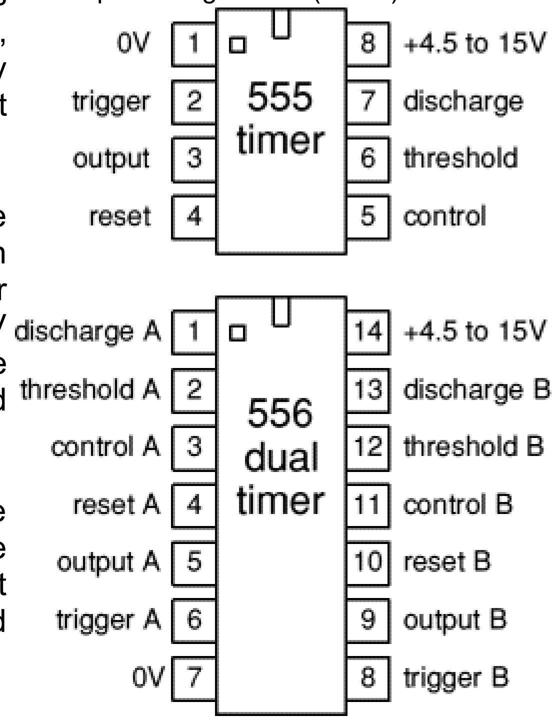
The principal reason for the success of the MOSFET was the development of digital CMOS logic, which uses p- and n-channel MOSFETs as building blocks. Overheating is a major concern in integrated circuits since ever more transistors are packed into ever smaller chips. CMOS logic reduces power consumption because no current flows (ideally), and thus no power is consumed, except when the inputs to logic gates are being switched. CMOS accomplishes this current reduction by complementing every nMOSFET with a pMOSFET and connecting both gates and both drains together. A high voltage on the gates will cause the nMOSFET to conduct and the pMOSFET not to conduct and a low voltage on the gates causes the reverse. During the switching time as the voltage goes from one state to another, both MOSFETs will conduct briefly. This arrangement greatly reduces power consumption and heat generation. Digital and analog CMOS applications are described below.

Introduction – IC 555 & 556



Example circuit symbol (above)

Actual pin arrangements (below)



The 8-pin 555 timer must be one of the most useful ICs ever made and it is used in many projects. With just a few external components it can be used to build many circuits, not all of them involve timing!

A popular version is the NE555 and this is suitable in most cases where a '555 timer' is specified. The 556 is a dual version of the 555 housed in a 14-pin package, the two timers (A and B) share the same power supply pins. The circuit diagrams on this page show a 555, but they could all be adapted to use one half of a 556.

Low power versions of the 555 are made, such as the ICM7555, but these should only be used when specified (to increase battery life) because their maximum output current of about 20mA (with a 9V supply) is too low for many standard 555 circuits. The ICM7555 has the same pin arrangement as a standard 555.

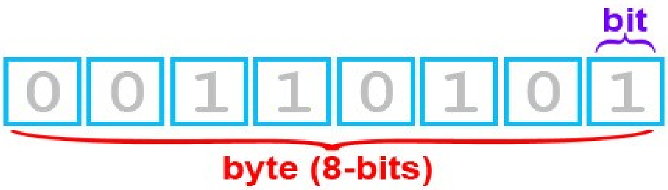
The circuit symbol for a 555 (and 556) is a box with the pins arranged to suit the circuit diagram: for example 555 pin 8 at the top for the +Vs supply, 555 pin 3 output on the right. Usually just the pin numbers are used and they are not labelled with their function.

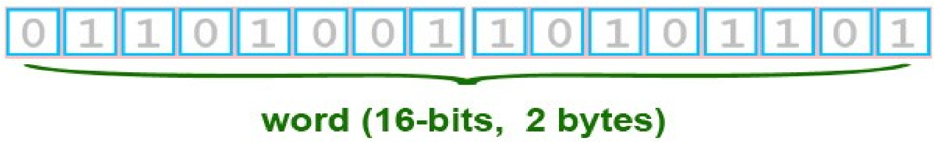
The 555 and 556 can be used with a supply voltage (Vs) in the range 4.5 to 15V (18V absolute maximum).

Standard 555 and 556 ICs create a significant 'glitch' on the supply when their output changes state. This is rarely a problem in simple circuits with no other ICs, but in more complex circuits a **smoothing capacitor** (eg 100µF) should be connected across the +Vs and 0V supply near the 555 or 556.

The input and output pin functions are described briefly below and there are fuller explanations covering the various circuits:

BIT





A **bit** or **binary digit** is the basic unit of information in computing and telecommunications. The two values can also be interpreted as logical values (*true*/*false*, *yes*/*no*), algebraic signs (+/−), activation states (*on*/*off*), or any other two-valued attribute. In several popular programming languages, numeric 0 is equivalent (or convertible) to logical *false*, and 1 to *true*.

There are several units of information which are defined as multiples of bits, such as byte (8 bits), kilobit (either 1000 or 2^{10} = 1024 bits), megabyte (either 8000000 or 8×2^{20} = 8388608bits), etc.

v • d • e

Multiples of bits

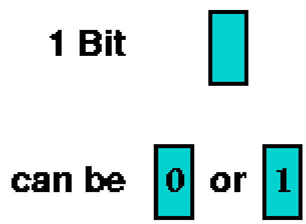
SI decimal prefixes			IEC binary prefixes	
Name (Symbol)	**Standard SI**	**Binary usage**	**Name (Symbol)**	**Value**
kilobit (kbit)	10^3	2^{10}	kibibit (Kibit)	2^{10}
megabit (Mbit)	10^6	2^{20}	mebibit (Mibit)	2^{20}
gigabit (Gbit)	10^9	2^{30}	gibibit (Gibit)	2^{30}
terabit (Tbit)	10^{12}	2^{40}	tebibit (Tibit)	2^{40}
petabit (Pbit)	10^{15}	2^{50}	pebibit (Pibit)	2^{50}
exabit (Ebit)	10^{18}	2^{60}	exbibit (Eibit)	2^{60}
zettabit (Zbit)	10^{21}	2^{70}	zebibit (Zibit)	2^{70}
yottabit (Ybit)	10^{24}	2^{80}	yobibit (Yibit)	2^{80}

Byte

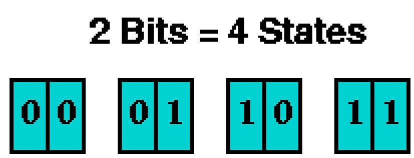
Binary Arithmetic

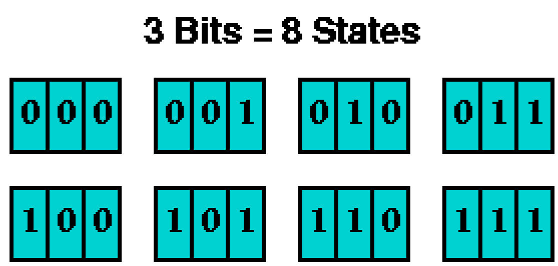
For some important aspects of Internet engineering, most notably IP Addressing, an understanding of binary arithmetic is critical. Many strange-looking decimal numbers can only be understood by converting them (at least mentally) to binary.

All digital computers represent data as a collection of *bits*. A bit is the smallest possible unit of information. It can be in one of two states - off or on, 0 or 1. The meaning of the bit, which can represent almost anything, is unimportant at this point. The thing to remember is that *all* computer data - a text file on disk, a program in memory, a packet on a network - is ultimately a collection of bits.



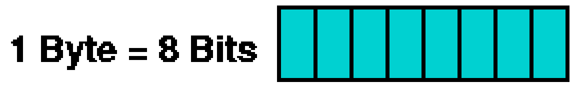
If one bit has two different states, how many states do two bits have? The answer is four. Likewise, three bits have eight states. For example, if a computer display had eight colors available, and you wished to select one of these to draw a diagram in, three bits would be sufficient to represent this information. Each of the eight colors would be assigned to one of the three-bit combinations. Then, you could pick one of the colors by picking the right three-bit combination.



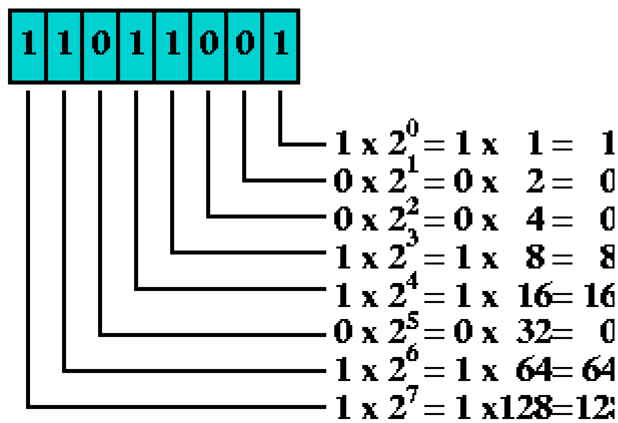


A common and convenient grouping of bits is the *byte* or *octet*, composed of eight bits. If two bits have four combinations, and three bits have eight combinations, how many combinations do eight bits have? If you don't want to write out all the possible byte patterns, just multiply eight twos together - one two for each bit. Two times two is four, so the number of combinations of two bits is four. Two times two times two is eight, so the number of

combinations of three bits is eight. Do this eight times - or just compute two to the eighth power - and you discover that a byte has 256 possible states.



Obviously, if a byte has 256 possible states, its exact state can be represented by a number from 1 to 256. However, since zero is a very important number, a byte is more typically represented by a number from 0 to 255. This is very common, and with bit pattern 00000000 representing zero, and bit pattern 11111111 representing 255. The numbers matching these two patterns, and everything in between, can be computed by assigning a weight to each bit, multiplying each bit's value (0 or 1) by its weight, and then adding the totals. For example, here's how 217 is represented as 11011001 in binary:



$$1 + 8 + 16 + 64 + 128 = 217$$

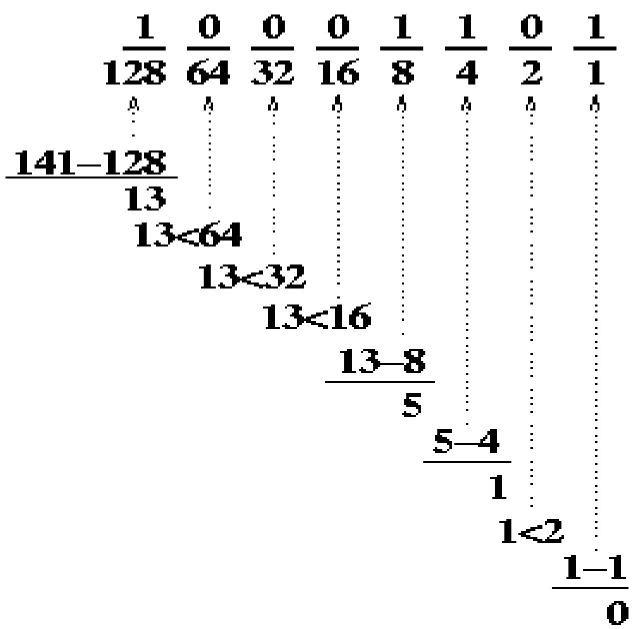
To convert a number from decimal to binary, begin at leftmost bit position (128). If the number is larger than or equal to the bit's weight, write a 1 in the bit position, subtract the bit's weight from the number, and continue with the difference. If the number is less than the bit's weight, write a 0 in the bit position and continue without any subtraction. Here's an illustration of converting 141 to binary:

There is a simpler way to convert bytes back and forth between binary and decimal; akin to memorizing multiplication tables. The byte can split into two four-bit halves, each half called a *nibble*. Memorize the decimal values for the high nibble (they're just the multiples of 16). The low nibble is trivial. Every number between 0 and 255 is the sum of one of the high nibble values and one of the low nibble values. Write the high nibble next to the low nibble, and you have the byte value in binary. Conversely, an eight-bit binary byte can be split in half, each nibble converted to decimal and two decimal numbers added together.

High Nibble		Low Nibble	High Nibble		Low Nibble
0	0 0 0 0	0	128	1 0 0 0	8
16	0 0 0 1	1	144	1 0 0 1	9
32	0 0 1 0	2	160	1 0 1 0	10
48	0 0 1 1	3	176	1 0 1 1	11
64	0 1 0 0	4	192	1 1 0 0	12
80	0 1 0 1	5	208	1 1 0 1	13
96	0 1 1 0	6	224	1 1 1 0	14
112	0 1 1 1	7	240	1 1 1 1	15

137 = 128 + 9 = 1 0 0 0 1 0 0 1

The most common bit patterns in Internet engineering are those with a string of one bits, followed by a string of zero bits. Here are all such bytes, along with their decimal representation, computed just like the example using 217.



1	1	1	1	1	1	1	1	255
1	1	1	1	1	1	1	0	254
1	1	1	1	1	1	0	0	252
1	1	1	1	1	0	0	0	248
1	1	1	1	0	0	0	0	240
1	1	1	0	0	0	0	0	224
1	1	0	0	0	0	0	0	192
1	0	0	0	0	0	0	0	128
0	0	0	0	0	0	0	0	0

Unit symbol or abbreviation

Prefixes for bit and byte multiples							
Decimal			**Binary**				
Value	**SI**		**Value**	**IEC**		**JEDEC**	
1000	k	kilo	1024	Ki	kibi	K	kilo
1000^2	M	mega	1024^2	Mi	mebi	M	mega
1000^3	G	giga	1024^3	Gi	gibi	G	giga
1000^4	T	tera	1024^4	Ti	tebi		
1000^5	P	peta	1024^5	Pi	pebi		
1000^6	E	exa	1024^6	Ei	exbi		
1000^7	Z	zetta	1024^7	Zi	zebi		
1000^8	Y	yotta	1024^8	Yi	yobi		

Nibble

In computing, a **nibble** (often, **nybble**, or even **nyble** to simulate the spelling of **byte**) is a four-bit aggregation,[1] or half an octet. As a nibble contains 4 bits, there are sixteen (2^4) possible values, so a nibble corresponds to a single hexadecimal digit (thus, it is often referred to as a "hex digit" or "hexit")A full byte (octet) is represented by two hexadecimal digits; therefore, it is common to display a byte of information as two nibbles. The nibble is often called a "semioctet" or a "quartet" in a networking or telecommunication context. Sometimes the set of all 256 byte values is represented as a table 16×16, which gives easily readable hexadecimal codes for each value.

The sixteen nibbles and their equivalents in other numeral systems:

$\mathbf{0}_{hex}$	=	0_{dec}	=	0_{oct}	0	0	0	0
$\mathbf{1}_{hex}$	=	1_{dec}	=	1_{oct}	0	0	0	1
$\mathbf{2}_{hex}$	=	2_{dec}	=	2_{oct}	0	0	1	0
$\mathbf{3}_{hex}$	=	3_{dec}	=	3_{oct}	0	0	1	1
$\mathbf{4}_{hex}$	=	4_{dec}	=	4_{oct}	0	1	0	0
$\mathbf{5}_{hex}$	=	5_{dec}	=	5_{oct}	0	1	0	1
$\mathbf{6}_{hex}$	=	6_{dec}	=	6_{oct}	0	1	1	0
$\mathbf{7}_{hex}$	=	7_{dec}	=	7_{oct}	0	1	1	1
$\mathbf{8}_{hex}$	=	8_{dec}	=	10_{oct}	1	0	0	0
$\mathbf{9}_{hex}$	=	9_{dec}	=	11_{oct}	1	0	0	1
$\mathbf{A}_{hex}$	=	10_{dec}	=	12_{oct}	1	0	1	0
$\mathbf{B}_{hex}$	=	11_{dec}	=	13_{oct}	1	0	1	1
$\mathbf{C}_{hex}$	=	12_{dec}	=	14_{oct}	1	1	0	0
$\mathbf{D}_{hex}$	=	13_{dec}	=	15_{oct}	1	1	0	1
$\mathbf{E}_{hex}$	=	14_{dec}	=	16_{oct}	1	1	1	0
$\mathbf{F}_{hex}$	=	15_{dec}	=	17_{oct}	1	1	1	1

Logic gate

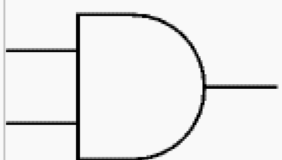
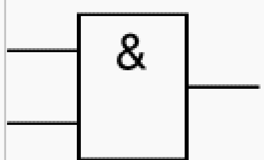
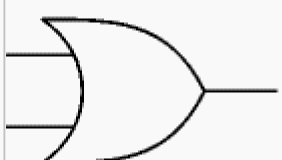
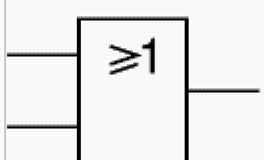
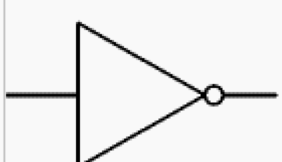
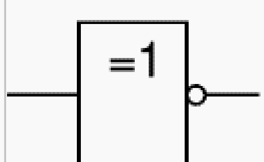
From Wikipedia, the free encyclopedia

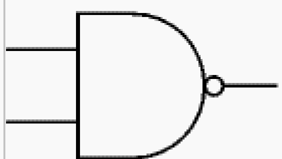
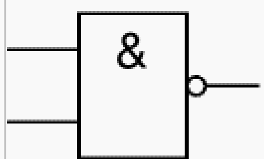
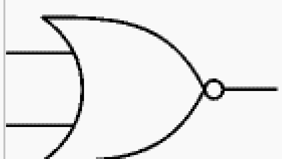
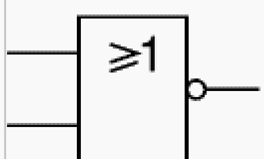
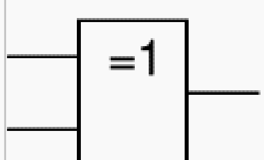
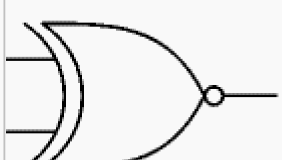
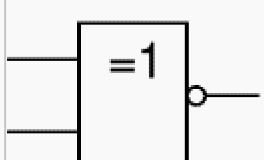
Jump to: navigation, search

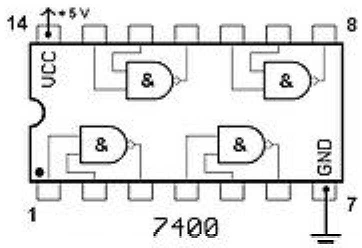
A **logic gate** performs a logical operation on one or more logic inputs and produces a single logic output. The logic normally performed is Boolean logic and is most commonly found in digital circuits.

Logic gates are primarily implemented electronically using diodes or transistors, but can also be constructed using electromagnetic relays, fluidics, optics, molecules, or even mechanical elements.

In electronic logic, a logic level is represented by a voltage or current, (which depends on the type of electronic logic in use). Each logic gate requires power so that it can source and sink currents to achieve the correct output voltage. In logic circuit diagrams the power is not shown, but in a full electronic schematic, power connections are required

<table>
<tr><th>Type</th><th>Distinctive shape</th><th>Rectangular shape</th><th>Boolean algebra between A& B</th><th>Truth table</th></tr>
<tr><td>AND</td><td></td><td>
</td><td>A * B</td><td><table><tr><th colspan="2">INPUT</th><th>OUTPUT</th></tr><tr><td>A</td><td>B</td><td>A AND B</td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td></tr>
<tr><td>OR</td><td></td><td>
</td><td>$A + B$</td><td><table><tr><th colspan="2">INPUT</th><th>OUTPUT</th></tr><tr><td>A</td><td>B</td><td>A OR B</td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td></tr>
<tr><td>NOT</td><td></td><td>
</td><td>As a Inverter</td><td><table><tr><th>INPUT</th><th>OUTPUT</th></tr><tr><td>A</td><td>NOT A</td></tr><tr><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td></tr></table></td></tr>
<tr><td colspan="5">In electronics a NOT gate is more commonly called an inverter. The circle on the symbol is called a bubble, and is generally used in circuit diagrams to indicate an inverted (active-low) input or output.</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>NAND</td><td></td><td>
</td><td>A * B = A* B</td><td><table><tr><th colspan="2">INPUT</th><th>OUTPUT</th></tr><tr><td>A</td><td>B</td><td>A NAND B</td></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td></tr>
<tr><td>NOR</td><td></td><td>
</td><td>–</td><td><table><tr><th colspan="2">INPUT</th><th>OUTPUT</th></tr><tr><td>A</td><td>B</td><td>A NOR B</td></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td></tr>
<tr><td>XOR</td><td></td><td>
</td><td>–</td><td><table><tr><th colspan="2">INPUT</th><th>OUTPUT</th></tr><tr><td>A</td><td>B</td><td>A XOR B</td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td></tr>
<tr><td>XNOR</td><td></td><td>
</td><td>–</td><td><table><tr><th colspan="2">INPUT</th><th>OUTPUT</th></tr><tr><td>A</td><td>B</td><td>A XNOR B</td></tr><tr><td>0</td><td>0</td><td>1</td></tr></table></td></tr>
</table>

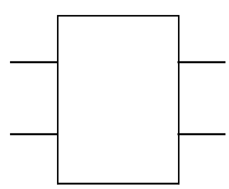


Flip-flop

In digital circuits, a flip-flop is a term referring to an electronic circuit (a bistable multivibrator) that has two stable states and thereby is capable of serving as one bit of memory. Today, the term flip-flop has come to mostly denote non-transparent (clocked or edge-triggered) devices, while the simpler transparent ones are often referred to as latches; however, as this distinction is quite new, the two words are sometimes used interchangeably (see history).

A flip-flop is usually controlled by one or two control signals and/or a gate or clock signal. The output often includes the complement as well as the normal output. As flip-flops are implemented electronically, they require power and ground connections.

Set-Reset flip-flops (SR flip-flops)



Set

Re Set

The symbol for an SR latch

The fundamental latch is the simple SR flip-flop , where S and R stand for set and reset respectively. It can be constructed from a pair of cross-coupled NOR logic gates. The stored bit is present on the output marked Q.

Normally, in storage mode, the S and R inputs are both low, and feedback maintains the Q and Q outputs in a constant state, with Q the complement of Q. If S (Set) is pulsed high while R is held low, then the Q output is forced high, and stays high even after S returns low; similarly, if R (Reset) is pulsed high while S is held low, then the Q output is forced low, and stays low even after R returns low.

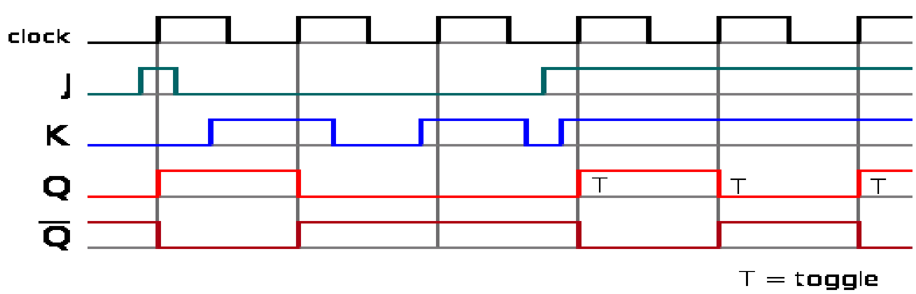
SR Flip-Flop operation

Characteristic table   Excitation table

S	R	Action	Q (t)	Q (t+1)	S	R	Action
0	0	Keep state	0	0	0	X	No change
0	1	Q = 0	0	1	1	0	set
1	0	Q = 1	1	0	0	1	reset
1	1	Unstable combination, see race condition	1	1	X	0	No change

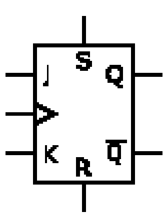
('X' denotes a don't care condition; meaning the signal is irrelevant)

JK flip-flop



JK flip-flop timing diagram

The JK flip-flop augments the behavior of the SR flip-flop (J=Set, K=Reset) by interpreting the S = R = 1 condition as a "flip" or toggle command. Specifically, the combination J = 1, K = 0 is a command to set the flip-flop; the combination J = 0, K = 1 is a command to reset the flip-flop; and the combination J = K = 1 is a command to toggle the flip-flop, i.e., change its output to the logical complement of its current value. Setting J = K = 0 does NOT result in a D flip-flop, but rather, will hold the current state. To synthesize a D flip-flop, simply set K equal to the complement of J. The JK flip-flop is therefore a universal flip-flop, because it can be configured to work as an SR flip-flop, a D flip-flop, or a T flip-flop. NOTE: The flip flop is positive edge triggered (Clock Pulse) as seen in the timing diagram.



A circuit symbol for a JK flip-flop, where > is the clock input, J and K are data inputs, Q is the stored data output, and Q' is the inverse of Q.

The characteristic equation of the JK flip-flop is:

$$Q_{next} = J\overline{Q} + \overline{K}Q$$

and the corresponding truth table is:

JK Flip Flop operation

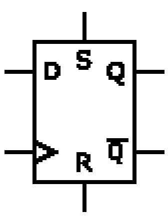
Characteristic table

J	K	Qnext	Comment
0	0		hold state
0	1		reset 0
1	0		set 1
1	1		toggle 1

Excitation table

Q	Qnext	J	K	Comment
0	0	0	X	No change
1	1	X	Set	
0	X	1	Reset	
1	X	0	No change	

D flip-flop



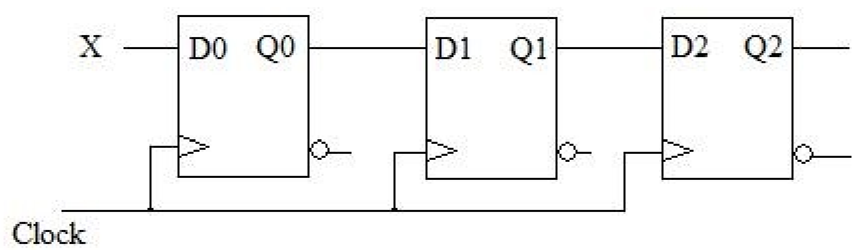
D flip-flop symbol

The Q output always takes on the state of the D input at the moment of a rising clock edge (or falling edge if the clock input is active low). It is called the D flip-flop for this reason, since the output takes the value of the D input or Data input, and Delays it by one clock count. The D flip-flop can be interpreted as a primitive memory cell, zero-order hold, or delay line.

Truth table:

Clock	D	Q	Qprev
Rising edge	0	0	X
Rising edge	1	1	X
Non-Rising	X	Qprev	

('X' denotes a Don't care condition, meaning the signal is irrelevant)



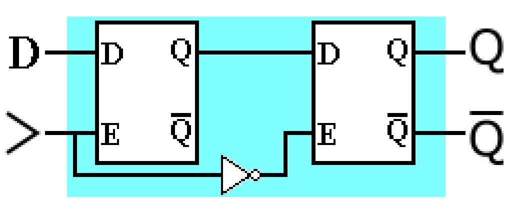
3-bit shift register

These flip flops are very useful, as they form the basis for shift registers, which are an essential part of many electronic devices. The advantage of the D flip-flop over the D-type latch is that it "captures" the signal at the moment the clock goes high, and subsequent changes of the data line do not influence Q until the next rising clock edge. An exception is that some flip-flops have a 'reset' signal input, which will reset Q (to zero), and may be either asynchronous or synchronous with the clock.

The above circuit shifts the contents of the register to the right, one bit position on each active transition of the clock. The input X is shifted into the leftmost bit position.

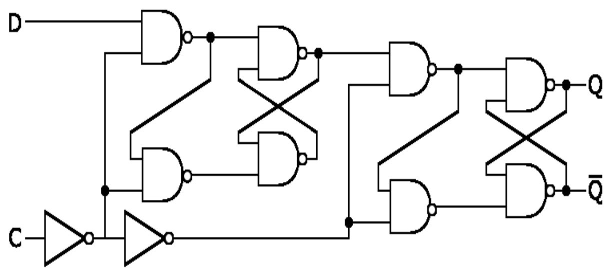
Master-slave (pulse-triggered) D flip-flop

A master-slave D flip-flop is created by connecting two gated D latches in series, and inverting the enable input to one of them. It is called master-slave because the second latch in the series only changes in response to a change in the first (master) latch. The term pulse triggered means that data are entered on the rising edge of the clock pulse, but the output doesn't reflect the change until the falling edge of the clock pulse.



A master slave D flip flop. It responds on the negative edge of the enable input (usually a clock).

For a positive-edge triggered master-slave D flip-flop, when the clock signal is low (logical 0) the “enable” seen by the first or “master” D latch (the inverted clock signal) is high (logical 1). This allows the “master” latch to store the input value when the clock signal transitions from low to high. As the clock signal goes high (0 to 1) the inverted “enable” of the first latch goes low (1 to 0) and the value seen at the input to the master latch is “locked”. Nearly simultaneously, the twice inverted “enable” of the second or “slave” D latch transitions from low to high (0 to 1) with the clock signal. This allows the signal captured at the rising edge of the clock by the now “locked” master latch to pass through the “slave” latch. When the clock signal returns to low (1 to 0), the output of the "slave" latch is "locked", and the value seen at the last rising edge of the clock is held while the “master” latch begins to accept new values in preparation for the next rising clock edge.



An implementation of a master-slave D flip-flop that is triggered on the positive edge of the clock.

By removing the left-most inverter in the above circuit, a D-type flip flop that strobes on the falling edge of a clock signal can be obtained. This has a truth table like this:

D	Q	>	Qnext
0	X	Falling	0
1	X	Falling	1

Most D-type flip-flops in ICs have the capability to be set and reset, much like an SR flip-flop. Usually, the illegal S = R = 1 condition is resolved in D-type flip-flops.

Inputs				Outputs	
S	R	D	>	Q	Q'
0	1	X	X	0	1
1	0	X	X	1	0
1	1	X	X	1	1

By setting S = R = 0, the flip-flop can be used as described above.

Edge-triggered D flip-flop

A more efficient way to make a D flip-flop is not so easy to understand, but it works the same way. While the master-slave D flip flop is also triggered on the edge of a clock, its components are each triggered by clock levels. The "edge-triggered D flip flop" does not have the master slave properties.

How to Solder

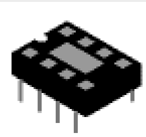
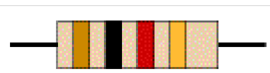
Soldering Advice for Components

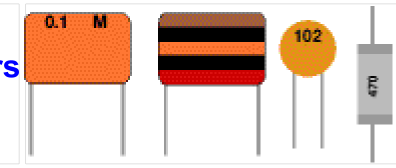
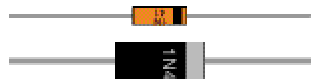
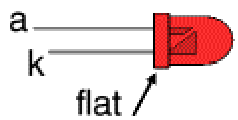
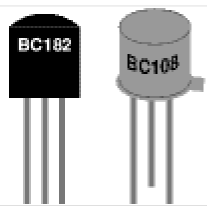
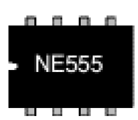
It is very tempting to start soldering components onto the circuit board straight away, but please take time to identify all the parts first. You are much less likely to make a mistake if you do this!

1. **Stick all the components onto a sheet of paper using sticky tape.**
2. **Identify each component** and write its name or value beside it.
3. **Add the code (R1, R2, C1 etc.) if necessary.** Many projects from books and magazines label the components with codes (R1, R2, C1, D1 etc.) and you should use the project's parts list to find these codes if they are given.
4. **Resistor values** can be found using the resistor colour code which is explained on our Resistors page. You can print out and make your own Resistor Colour Code Calculator to help you.
5. **Capacitor values** can be difficult to find because there are many types with different labelling systems! The various systems are explained on our Capacitors page.

Some components require special care when soldering. Many must be placed the correct way round and a few are easily damaged by the heat from soldering. Appropriate warnings are given in the table below, together with other advice which may be useful when soldering.

For most projects it is best to put the components onto the board in the order given below:

	Components	**Pictures**	**Reminders and Warnings**
1	**IC Holders** (DIL sockets)		**Connect the correct way round** by making sure the notch is at the correct end. Do NOT put the ICs (chips) in yet.
2	**Resistors**		No special precautions are needed with resistors.

3	**Small value capacitors** (usually less than 1μF)		These may be connected either way round. Take care with polystyrene capacitors because they are easily damaged by heat.
4	**Electrolytic capacitors** (1μF and greater)		**Connect the correct way round.** They will be marked with a + or - near one lead.
5	**Diodes**		**Connect the correct way round.** Take care with germanium diodes (e.g. OA91) because they are easily damaged by heat.
6	**LEDs**		**Connect the correct way round.** The diagram may be labelled **a** or **+** for anode and **k** or **-** for cathode; yes, it really is k, not c, for cathode! The cathode is the short lead and there may be a slight flat on the body of round LEDs.
7	**Transistors**		**Connect the correct way round.** Transistors have 3 'legs' (leads) so extra care is needed to ensure the connections are correct. Easily damaged by heat.
8	**Wire Links** between points on the circuit board.	 single core wire	Use single core wire, this is one solid wire which is plastic-coated. If there is no danger of touching other parts you can use tinned copper wire, this has no plastic coating and looks just like solder but it is stiffer.
9	**Battery clips**, **buzzers** and other parts with their own wires		**Connect the correct way round.**
10	**Wires** to parts off the circuit board, including **switches**, **relays**, **variable resistors** and **loudspeakers**.	 stranded wire	You should use stranded wire which is flexible and plastic-coated. Do not use single core wire because this will break when it is repeatedly flexed.
11	**ICs (chips)**		**Connect the correct way round.** **Many ICs are static sensitive.** Leave ICs in their antistatic packaging until you need them, then earth your hands by touching a metal water pipe or window frame before touching the ICs. **Carefully insert ICs in their holders**: make sure all the pins are lined up with the socket then push down firmly with your thumb.

CLASSIFICATION OF FLUXES

1. INORGANIX FLUX
2. ORGANIC FLUX
3. ROSIN BASED FLUX
4. NO CLEAN FLUX

1. INORGANIC FLUX:

Consist of mixture of salts/acids such as HCL, H3PO4, $Zncl_2$, Nh_4Cl, Na_2Bo, having picking action through generated HCI acid in contact with moisture or added water. These fluxes are very corrosive in nature and generally not used in electronic assemblies.

2. NON ROSIN BASED FLUXES

These fluxes do not contain Rosin but contain only activators based on GLIMTIC, LACTIC ACIDS/HYDROCHLORIDES, water soluble and meditatively corrosive, hence must be cleaned after soldering process thoroughly.

3. ROSIN BASED FLUXES

Rosin which is naturally available from pine a tree by tapping is made into crystalline structure with pale yellow to Dark brown colour is used as base.

Rosin is a mixture of several organic compounds like ABETIC ACID, PIMARIC ACID, etc., pure Rosin is a weak pickling agent. For heavier passivation layer, surface activators like Bromides/ chlorides are added. The acid contents for various R type of fluxes are given below.

R – ROSIN NON ACTIVATED.	ACID CONTENT: < 0.2%
RAM – ROSIN MILDLY ACTIVATED.	ACID CONTENT: 0.2% TO 0.4%
RA – ROSIN ACTIVATED.	ACID CONTENT: 0.4% to 4%
RSA – ROSIN SUPER ACTIVATED.	ACID CONTENT: > 4%

4. NO CLEAN FLUX

Does not contain natural Rosin but obtained by synthetic resins solvents, foaming agents and activators. Generally does not leave any residues.

1. SOLDER ALLOY

WHY TIN & LEAD

1. Tin is not appreciably affected by air or water.
2. The corrosion resistance of tin is an important factor for using as a coating on Copper wire to protect against corrosion.
3. Tin reacts and alloys with metal easily.
4. Lead is soft and dense, but surface gets quickly corroded.
5. Lead reduces the melting temperature and brittleness thus adding to the overall strength of alloy.

METALLURGY OF SOLDER JOINTS

When two metals “A” and “B” are soldered with a filler material “S”. The following regions occur in the final joint structure.

1. PURE “A”
2. ALLOY OF “A” AND “S”
3. PURE “S”
4. ALLOY OF “S” AND “B”
5. PURE “B”

The alloy region consists of irreversible compounds created out of the metals and the filler. The filler, the thickness of this alloy being 0.1 to 1.0 microns. This zone is usually called as intermetallic layer in case of Cu-Solder (sn-pb) combination. They are typically cu3sn, cu6sn5. This intermetallic layer is mainly responsible for the strength of the joint. This layer thickness increases with time and temperature of the soldering. This

intermatellic layer is brittle in nature. Hence the thickness of this layer has to be controlled.

CHEMICAL COMPOSITION OF Sn63, Sn60

	Sn63	**Sn60**
TIN Composition	: 62.5-62.5%	59.5% - 61.5%
Solid Melting Range	: 183 Deg.C	183 Deg.C
Liquid Melting range	: 183 Deg.C	188 Deg. C
Plastic Region	: Nil	Slight

What is solder?

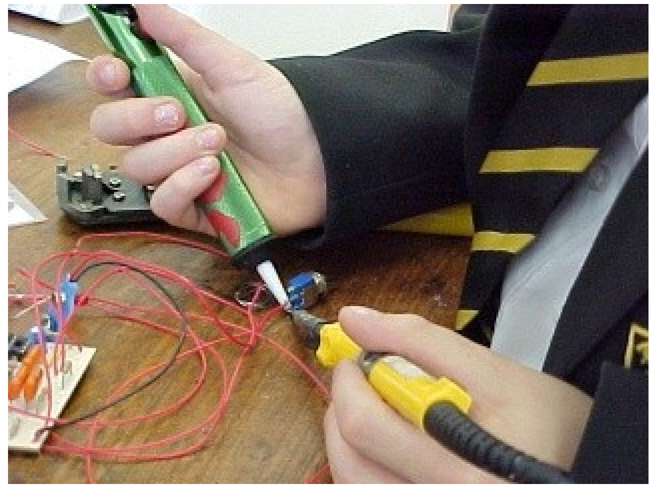
Reels of solder

Solder is an alloy (mixture) of tin and lead, typically 60% tin and 40% lead. It melts at a temperature of about 200°C. Coating a surface with solder is called 'tinning' because of the tin content of solder. Lead is poisonous and you should always wash your hands after using solder.

Solder for electronics use contains tiny cores of flux, like the wires inside a mains flex. The flux is corrosive, like an acid, and it cleans the metal surfaces as the solder melts. This is why you must melt the solder actually on the joint, not on the iron tip. Without flux most joints would fail because metals quickly oxidise and the solder itself will not

flow properly onto a dirty, oxidised, metal surface.

The best size of solder for electronics is 22swg (SWG= standard wire gauge).


Using a desoldering pump (solder sucker)

Desoldering

At some stage you will probably need to desolder a joint to remove or re-position a wire or component. There are two ways to remove the solder:

1. **With a desoldering pump (solder sucker)**

   - Set the pump by pushing the spring-loaded plunger down until it locks.
   - Apply both the pump nozzle and the tip of your soldering iron to the joint.
   - Wait a second or two for the solder to melt.
   - Then press the button on the pump to release the plunger and suck the molten solder into the tool.
   - Repeat if necessary to remove as much solder as possible.
   - The pump will need emptying occasionally by unscrewing the nozzle.

Solder remover wick

2. **With solder remover wick (copper braid)**

   - Apply both the end of the wick and the tip of your soldering iron to the joint.
   - As the solder melts most of it will flow onto the wick, away from the joint.
   - Remove the wick first, then the soldering iron.
   - Cut off and discard the end of the wick coated with solder.

After removing most of the solder from the joint(s) you may be able to remove the wire or component lead straight away (allow a few seconds for it to cool). If the joint will not come apart easily apply your soldering iron to melt the remaining traces of solder at the same time as pulling the joint apart, taking care to avoid burning yourself.

Soldering iron

For electronics work the best type is one powered by mains electricity (230V in the UK), it should have a heatproof cable for safety. The iron's power rating should be 15 to 25W and it should be fitted with a small bit of 2 to 3mm diameter.

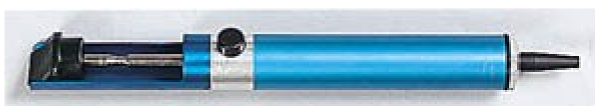
Other types of soldering iron

Low voltage soldering irons are available, but their extra safety is undermined if you have a mains lead to their power supply! **Temperature controlled** irons are excellent for frequent use, but not worth the extra expense if you are a beginner. **Gas-powered** irons are designed for use where no mains supply is available and are not suitable for everyday use. Pistol shaped **solder guns** are far too powerful and cumbersome for normal electronics use.

Soldering iron stand

You must have a safe place to put the iron when you are not holding it. The stand should include a sponge which can be dampened for cleaning the tip of the iron.

Desoldering pump (solder sucker)



A tool for removing solder when desoldering a joint to correct a mistake or replace a component.

Solder remover wick (copper braid)

This is an alternative to the desoldering pump shown above.

Reel of solder

The best size for electronics is 22swg
(SWG standardwire gauge).

Side cutters

For trimming component leads close to the circuit board.

Wire strippers

Most designs include a cutter as suitable for trimming

component leads.

Small pliers

Usually called 'snipe nose' pliers, these are for bending component leads etc. If you put a strong rubber band across the handles the pliers make a convenient holder for parts such as switches while you solder the contacts.

Small flat-blade screwdriver

For scraping away excess flux and dirt between tracks, as well as driving screws!

Heat sink

You can buy a special tool, but a standard crocodile clip works just as well and is cheaper.

The following tool is only required if you are using stripboard:

Track cutter

A 3mm drill bit can be used instead, in fact the tool is usually just a 3mm drill bit with a proper handle fitted.

The following tools are only required if you make your own PCBs:

PCB rubber

This is an abrasive rubber for cleaning PCBs. It can also be used to clean strip board where the copper tracks have become dull and tarnished.

Breadboard

A breadboard (solder less breadboard, protoboard, plug board) is reusable sometimes [1] solder less device used to build a (generally temporary) prototype of an electronic circuit and for experimenting with circuit designs. This is in contrast to strip board (Vero board) and similar prototyping printed circuit boards, which are used to build more permanent soldered prototypes or one-offs, and cannot easily be reused. A variety of electronic systems may be prototyped by using breadboards, from small analog and digital circuits to complete central processing units (CPUs).

The term breadboard is derived from an early form of point-to-point construction: in particular, the practice of constructing simple circuits (usually using valves/tubes) on a convenient wooden base, similar to a cutting board like the kind used for slicing bread with a knife. It can also be viewed as bread with a large number of pores (holes for connection); like the bread most commonly used in America and Europe, a modern prototyping board is typically white or off-white.

Jump wires

The jump wires for breadboarding can be obtained in ready-to-use jump wire sets or can be manually manufactured. The latter can become tedious work for larger circuits. Ready-to-use jump wires come in different qualities, some even with tiny plugs attached to the wire ends. Jump wire material for ready-made or home-made wires should usually be 22 AWG (0.33 mm^2) solid copper, tin-plated wire - assuming no tiny plugs are to be attached to the wire ends. The wire ends should be stripped 3/16" to 5/16" (approx. 5 mm to 8 mm). Shorter stripped wires might result in bad contact with the board's spring clips (insulation being caught in the springs). Longer stripped wires increase the likelihood of short-circuits on the board. Needle-nose pliers and tweezers are helpful when inserting or removing wires, particularly on crowded boards.

Differently colored wires and color coding discipline are often adhered to for consistency. However, the number of available colors is typically far less than the number of signal types or paths. So typically a few wire colors get reserved for the supply voltages and ground (e.g. red, blue, black), some more for main signals, while the rest often get random colors. There are ready-to-use jump wire sets on the market where the color indicates the length of the wires; however, these sets do not allow applying a meaningful color coding schema.

Diagram

A "full size" terminal breadboard strip typically consists of around 56 to 65 rows of connectors, each row containing the above mentioned two sets of connected clips (A to E and F to J). "Small size" strips typically come with around 30 rows.

Terminal Strip: **Breadboard**

```
  A B C D E   F G H I J

 1 o-o-o-o-o v o-o-o-o-o
 2 o-o-o-o-o   o-o-o-o-o
 3 o-o-o-o-o   o-o-o-o-o
 ~
 ~
61 o-o-o-o-o   o-o-o-o-o
62 o-o-o-o-o   o-o-o-o-o
63 o-o-o-o-o ^ o-o-o-o-o
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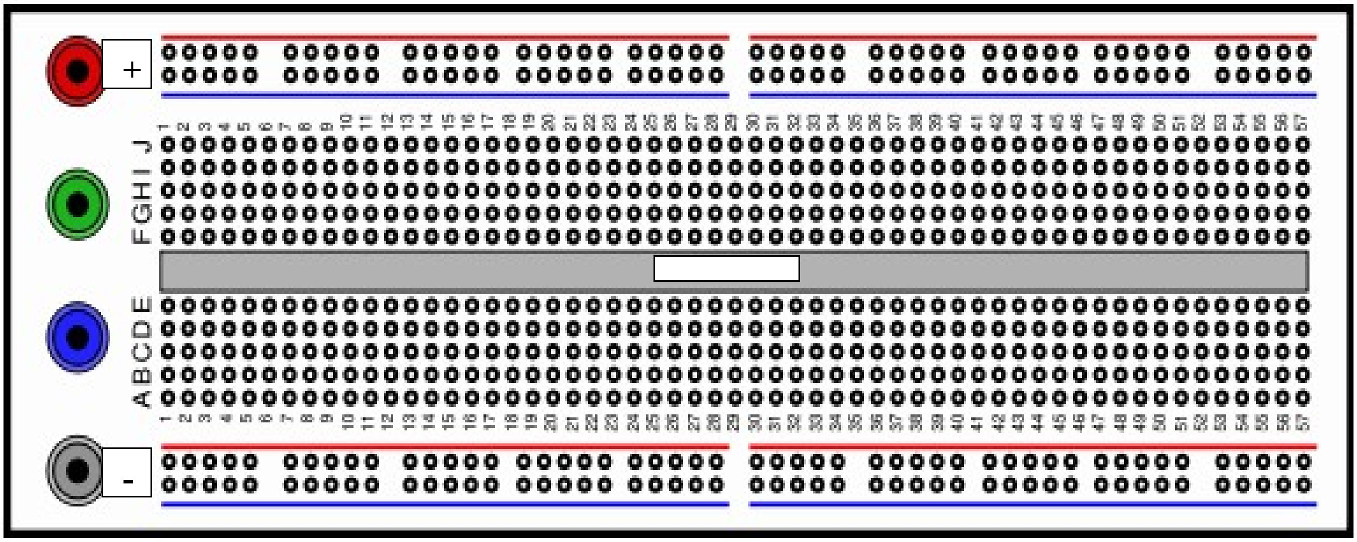

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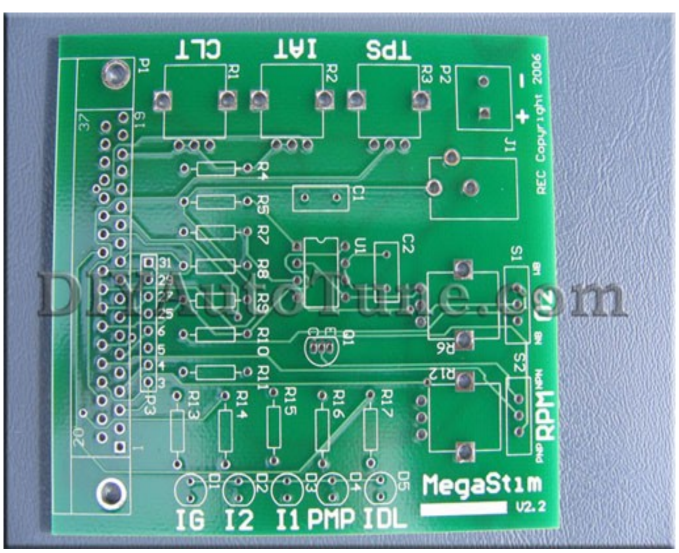
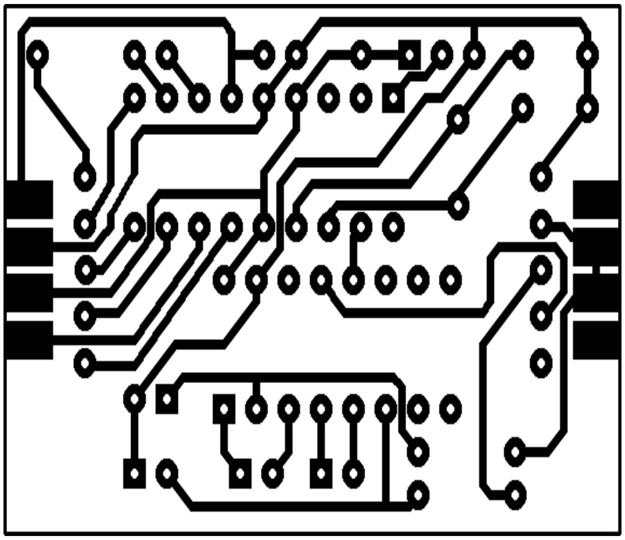
Printed circuit board (PCB)





PCBs are boards whereupon electronic circuits have been etched. PCBs are rugged, inexpensive, and can be highly reliable. They require much more layout effort and higher initial cost than either wire-wrapped or point-to-point constructed circuits, but are much cheaper and faster for high-volume production. Much of the electronics industry's PCB design, assembly, and quality control needs are set by standards that are published by the IPC organization.

ELECTRONIC PRODUCTS

Consisting of electronic assemblies, a combination of electronic components and devices and PCBs. Components need to be interconnected for their functioning, to get the desired results.

Generally, these components are mounted on Printed wiring board which provides support and required interconnection.

ABOUT THE PCB

Printed wiring Board, an essential part of total electronic packaging system, which provides interconnection between components, and physical support for the whole assembly. Various types and configuration of components are mounted on Printed wiring board to make the board functional as an electronic device.

The printed wiring boards are classified as follows:

i. Single sided
ii. Double sided
iii. Multi layer
iv. Flexible

The single sided PCB is the simplest, and has the conductor pattern printed only on one side. The components are inserted and mounted on the other side of the PCB. The double sided PCB has conductor patterns on both sides and components are mounted on one side, while in a multilayer PCB has several layers of conductors which are sand witched together.

The PCB consists of conductor tracks of Solder plated copper and required size of Holes (or plated through holes) for mounting various components as per design.

The basic substrate for the PCBs is made up of one of the following insulating materials:

i. Paper phenol
ii. Glass epoxy
iii. Glass polyamide
iv. Ceramic

The flexible boards are generally made up of polyamide substrate.

The Ceramic substrate is generally used in Defense applications where the ceramic components are used.

SOLDER MASK: Solder mask is applied on the Bare printed Circuit board for avoiding solder coating on unwanted conductor tracks during wave soldering and preventing conductor tracks from exposing to atmosphere. Normal conformal coating materials are

1. Acrylic
2. Polyurethane
3. Silicone
4. Paraxylylene
5. Epoxy

These coatings are applied by means of dipping, spraying, brushing or vacuum deposition depending upon material used.

Surface-mount technology

Surface-mount technology (**SMT**) is a method for constructing electronic circuits in which the components (SMC or Surface Mounted Components) are mounted directly onto the surface of printed circuit boards (PCBs). Electronic devices so made are called *surface-mount devices* or **SMD**s. In the industry it has largely replaced the through-hole technology construction method of fitting components with wire leads into holes in the circuit board.

An SMT component is usually smaller than its through-hole counterpart because it has either smaller leads or no leads at all. It may have short pins or leads of various styles, flat contacts, a matrix of solder balls (BGAs), or terminations on the body of the component.